Atomic Energy Control Board
P.O. Box 1046
Ottawa, Canada
K1P 5S9

Commission de contrôle de l'énergie atomique
C.P. 1046
Ottawa, Canada
K1P 5S9

INFO-0413

OFFSET RIVER TERRACE IN THE CHARLEVOIX SEISMIC ZONE

(AECB Project No. 3.139.1)

by

J.Y. Chagnon
and
J. Locat
Department of Geology
Laval University

A research report prepared for the
Atomic Energy Control Board
Ottawa, Canada

April 1992

MAGNEC
AMNEC

Multi-Agency Group for Neotectonics in Eastern Canada
L'Association Multipartite pour la Néotectonique dans l'Est Canadien

Contribution No. 91-02

Canada

Research report

92-04390/

OFFSET RIVER TERRACE IN THE CHARLEVOIX SEISMIC ZONE

A report prepared by J.Y. Chagnon and J. Locat, Department of Geology, Faculty of Science and Engineering, Université Laval, under contract to the Atomic Energy Control Board.

ABSTRACT

A tilted terrace at a maximum elevation of 141 m on the eastern wall of the Du Gouffre River valley, near Baie-St-Paul, Quebec, was investigated in order to determine the orientation of the layered units within the terrace on each side of a lineament which cuts through it.

The work completed in the Summer and Fall of 1990 involved surveying (levelling), trenching, a ground-probing radar survey, the analysis of the material shown along the wall of the excavations and an attempt to correlate the units on each segment of the terrace. The results indicate that the terrace is a marine or estuarine feature which now has a sloping surface (from 2.1 to 3.21 degrees over a length of 1256 m), that the internal layering is also similarly inclined, which has resulted in a rotation of the orientation of the layers, that the two segments of the terrace show no vertical offset but show indirect evidence of a lateral offset of about 20 m with a right lateral displacement. The origin of the tilting is tectonic. The age and rate of tilting are unknown, but the age is less than 9000 years.

RÉSUMÉ

Une terrasse inclinée sur le versant est de la vallée de la rivière du Gouffre, près de Baie-St-Paul (Québec), à une altitude maximale de 141 m, a été étudiée afin de déterminer l'orientation des couches de la terrasse, de part et d'autre d'une discontinuité linéaire qui la sépare en deux.

Les travaux exécutés pendant l'été et l'automne 1990 comprenaient l'arpentage (nivellement), l'excavation de tranchées, un levé de géoradar, l'analyse des matières observées sur les parois des excavations et une tentative de corrélation des couches de part et d'autre de la discontinuité. Les résultats indiquent que la terrasse est d'origine marine ou estuarine et que sa surface est maintenant inclinée vers le nord de 2,1 à 3,21 degrés sur une longueur de 1256 m; que les lits sous la surface ont à peu près la même pente, mais que leur orientation intiiale a subi l'effet d'une rotation; que les deux parties de la terrasse ne sont pas déplacées verticalement, mais ont un rejet horizontal de 20 m selon un mouvement latéral dextre. La cause de l'inclinaison est tectonique. L'âge et le taux d'inclinaison sont inconnus, mais l'âge est moindre que 9000 ans.

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I- INTRODUCTION

A- General Statement

Terraces of fluvial and marine origins, with a maximum age of 9,000 years are common along both sides of the lower reaches of Rivière du Gouffre. In this sector the river flows through the western edge of the Charlevoix seismic zone and drains into the St. Lawrence River at Baie St. Paul (Figure 1). The terraces are found at various levels from the bottom of the valley, near sea level, to a maximum altitude of 150 meters, which is below the upper limit of the Goldthwait marine invasion at 190 meters (Dionne, 1979).

At the eastern limit of the city of Baie St. Paul, on the east shore of Rivière Du Gouffre a well-defined and highly visible terrace near the top of the steep slope of the valley at a maximum elevation of 141 meters, with a length of over 1250 meters appears to be tilted upstream, towards the north. It also appears to be displaced vertically and laterally along a lineament, now occupied by an entrenched stream, which separates it in two segments of unequal lengths. The apparent lateral displacement is visible on air photographs where the two segments appear to be out of alignment. The vertical displacement is also discernible from

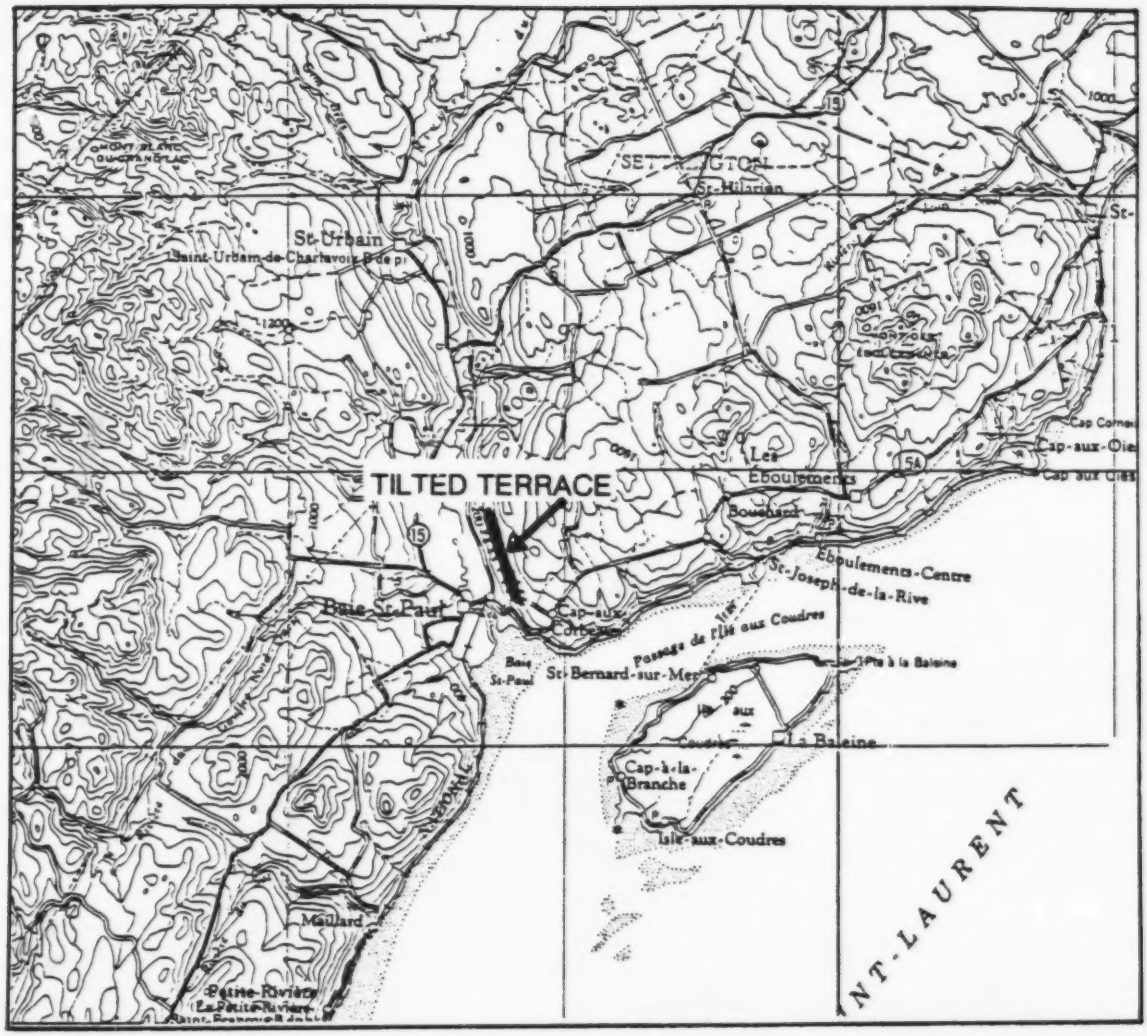


FIGURE 1

LOCATION OF THE BAIE ST-PAUL AREA AND OF THE TILTED TERRACE

Scale 1:250,000 **FROM: NTS, OTTAWA**

across the valley where the two segments appear to be discontinuous (Photograph 1). These two observations suggest that recent tectonic activity may have tilted and displaced segments of this terrace which was created not more than 9,000 years ago (Dionne, 1979, Lajoie, 1981). This probable neotectonic feature may be associated with the seismic activity in the Charlevoix seismic zone which is considered to be the most historically active seismic zone in North America (Adams and Basham, 1989). It is therefore of interest to verify the above mentioned observations, that is the tilting and displacement of the terrace, in order to establish the possibility of neotectonic activity at this location.

B- Geological setting

The bedrock in the Baie St. Paul area was mapped by Rondot (1969, 1972, 1979, 1989). The unconsolidated deposits have been located by Rondot (1969, 1972, 1979) and mapped in greater detail in the Baie St. Paul area by Chagnon (1969). Lajoie (1981) also studied the surficial deposits as part of a landslide susceptibility mapping project. Dionne (1979) published the results of a study of the extent of the Goldthwait marine invasion in the area.

1- Bedrock

In the vicinity of Baie St. Paul, highly folded and metamorphosed Precambrian rocks are overlain unconformably by Trenton limestones and shales of middle Ordovician age. The Ordovician rocks outcrop in the vicinity of the terraces on the east shore of Rivière Du Gouffre.

The bedrock is cut by a complex system of faults and joints with dominant subvertical east-southeast and north-northeast strikes and south-dipping northeast strikes (Rondot, 1972). The structural pattern resulted from rifting (Kumarapeli and Saull, 1966) related to the opening of the Iapetus Ocean at the end of the Precambrian during which time the major faults such as the St. Lawrence Rift and the Saguenay Graben are believed to have formed.

These faults have most likely been rejuvenated throughout geological time.

This area is also located at the southern edge of the Charlevoix seismic zone, as delineated by Anglin (1984), which corresponds to the southern limit of the Charlevoix impact structure. This feature which was created by a meteorite impact about 350 m.y. ago (Rondot, 1971) that superimposed its own structural pattern on the existing geological setting. Baie St. Paul occurs within a large annular depression (56 km in diameter) in which is located the valley of Rivière Du Gouffre. In the vicinity of Baie St. Paul the ground morphology corresponds to the geological conditions resulting from the impact structure and the valley occupies the annular depression. According to studies by Leblanc et al. (1973) and Leblanc and Buchbinder (1977) it is the seat of seismic activity located along normal faults in the Precambrian rocks.

Rondot (1979) showed linear elements (faults, joints) in the vicinity of the tilted terrace northeast of Baie St. Paul (Figures 2 and 3) and a northwest trending lineament which appears to intersect the terrace. A more detailed map of the geology of the area (Rondot, 1989) does not show these faults but does show geological discontinuities in the vicinity of the terrace (Figure 4).

2- Surficial

Glacial and postglacial deposits cover the bedrock almost completely along the lower reaches of Rivière Du Gouffre (Rondot, 1969, 1972). The tilted terrace is within the limits of the postglacial marine sediments deposited by the Goldthwait sea which invaded the area about 12,500 to 12,000 years B.P. (Dionne, 1979). At the beginning of the invasion, a glacio-marine phase, lasting from 500 to 1500 years, was marked by deltaic deposits. A transgressive phase lasting 2000 to 3000 years was then followed by a regressive episode beginning from 9,000 to 8,000 years B.P. The highest elevation of the sea in the area was 190 m, according to Lajoie (1981), and 200 m, according to Rondot (1989), before the Saint-Narcisse readvance (12,500 y. B.P.) and 150 m afterwards (165 m according to Rondot, 1989). This last level

FIGURE 2

MAP SHOWING THE FAULTS AND LINEAMENTS IN THE CHARLEVOIX AREA

FROM: RONDOT, 1979 (DPV-682)

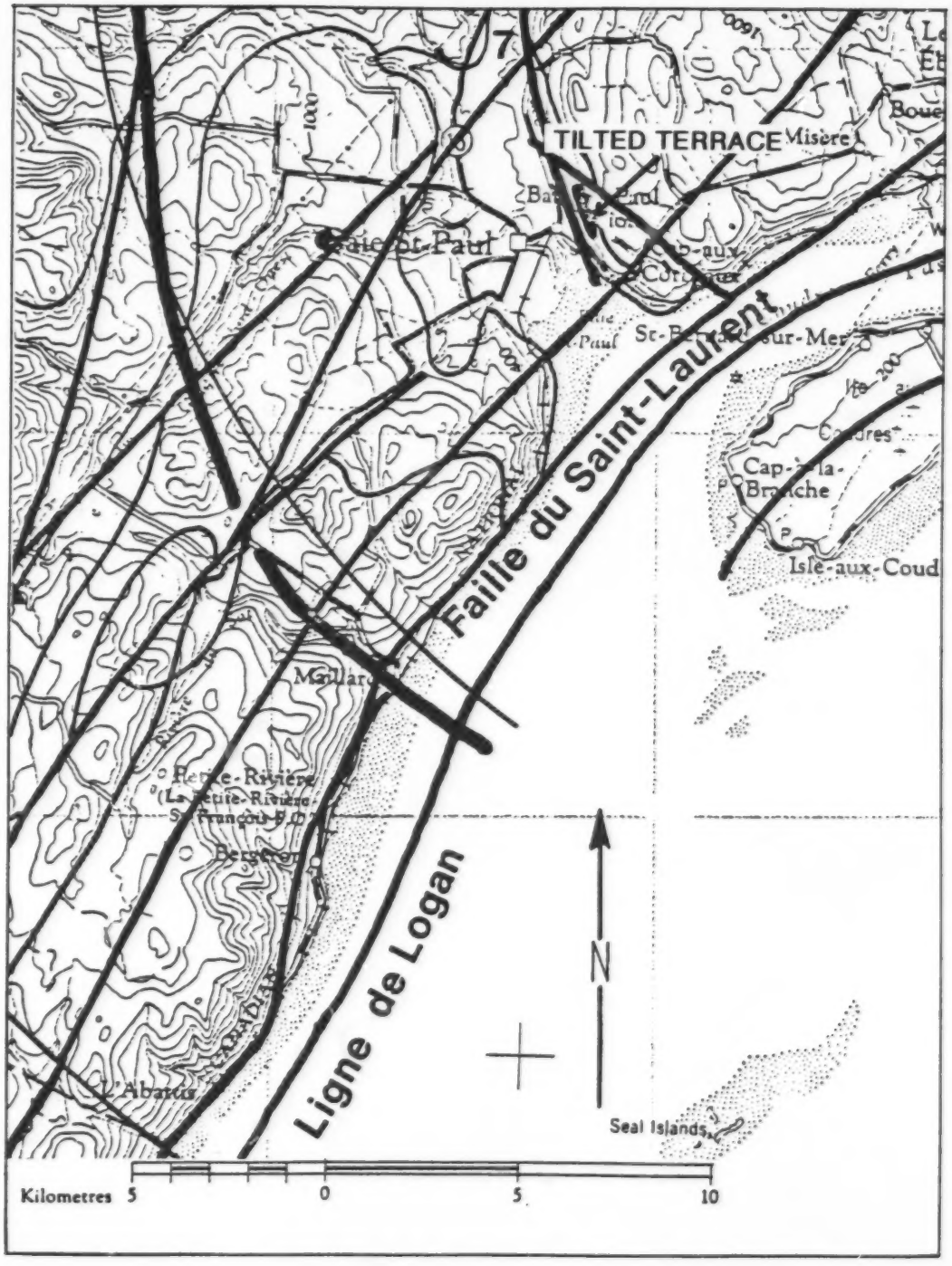


FIGURE 3

MAP SHOWING THE FAULTS AND LINEAMENTS IN THE BAIE-ST-PAUL AREA

FROM: RONDOT, 1979 (DPV-682)

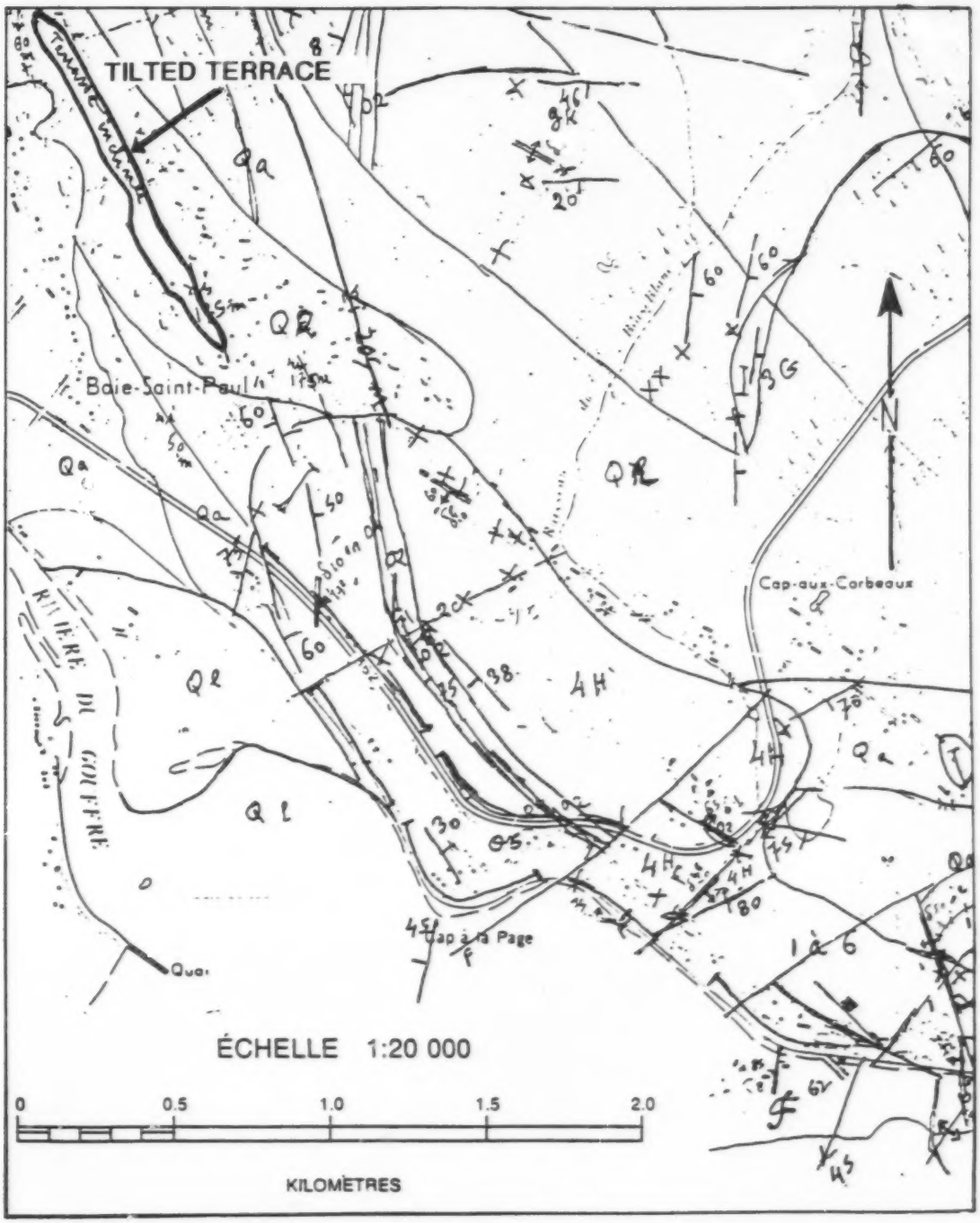


FIGURE 4

DETAILED GEOLOGICAL MAP OF THE BAIE ST. PAUL AREA SHOWING THE FAULTS AND THE STRATIGRAPHIC CONTACTS

FROM: RONDOT, 1989 (MB 89-21)

is well defined in the Charlevoix area. The various stages of the isostatic uplift of the land are outlined by a series of terraces at elevations of 140-145 m, 125 m, 95 m, 85 m (Rondot, 1989). These terraces are often made up of sandy material over marine clays.

3- Neotectonics and Seismicity

Recent vertical movements of the crust have been measured in Laurentides Park to the north of Baie St. Paul. The central part of the Park is subsiding at a rate of 15 cm over 40 years, or 4mm/y, in relation to the shore of the St. Lawrence (Lambert and Vanicek, 1979). These vertical movements are superimposed on isostatic uplift due to unloading from the melting of the ice cover. According to Govare and Gangloff (1986) the rate of postglacial uplift was on the order of 5m per century between 11000 and 8500 BC, then decreased to a few centimeters per century from 6000 BC to the present.

No active faults have been identified in the Charlevoix seismic zone and no direct evidence of neotectonic activity has ever been reported. Rondot (1979) wrote that the Charlevoix impact structure, which is Devonian in age, and straddles the St. Lawrence River, appears to show a relative displacement to the northeast. Chagnon and Locat (1987, 1990) reported differences in elevation of a terrace across a normal fault in the annular graben of the meteor impact near La Malbaie. Dionne (1990) identified geomorphologic and stratigraphic evidence of neotectonic activity at Petite-Rivière St-François, 10 km west of Baie St. Paul, where a low terrace differs in age and altitude from one side of La Martine River to the other. There is, therefore, some indirect evidence of neotectonism in the Charlevoix seismic zone and in the vicinity of Baie St. Paul.

In preparation for this project we looked for geomorphic indicators in the Baie St. Paul area, such as abrupt changes of valley floor slope, disruption of drainage and stream patterns, river shifts, presence of escarpments, etc. Many features are visible that can easily be explained by the ongoing isostatic uplift and by dynamic erosional processes, such as the omnipresent landslides which have shaped the valley slopes. The only probable local

indication is that provided by the apparent tilting of the upper terrace on the eastern side of the valley which can not be explained by other processes.

Leblanc et al. (1973), and Leblanc and Buchbinder (1977) concluded that the seismic activity in the Charlevoix seismic zone is concentrated in a 70 X 40 km area centred in the St. Lawrence River, with hypocenters in the Precambrian rocks at an average focal depth of 11 km. They suggested that the conjunction of the impact structure and Logan's line could have some influence on the seismicity. Stevens (1980) evaluated and analyzed the epicenters of some of the larger earthquakes, which occurred between 1924 and 1978, and confirmed that they fell into two distinct areas which coincide with the ends of the 70 km long northeast trending zone of microearthquake activity. Again the conjunction of the Charlevoix impact crater and Logan's contact, or Logan's line (shown on figure 3) was emphasized as influencing the concentration of regional stress producing the larger earthquakes. Roy and DuBerger (1983) concluded that the microearthquakes occur along the normal faults which characterize the St. Lawrence Lowlands and that they are related to the impact structure. They indicated that only the St. Lawrence Lowlands tectonic terrain is seismically active and this in areas affected by the impact structure. Lamontagne (1987) proposed that the meteor impact weakened the rift faults and introduced its own fractures. The earthquake activity is probably concentrated along these weak fault surfaces. The seismic signatures of the meteor impact are due to the presence of weakened paleorift faults. These faults are now being reactivated by the ongoing tectonic plate movements with resulting stresses even in intraplate areas.

Adams and Basham (1989) indicated that focal mechanisms represent thrust or combination thrust/strike-slip faulting resulting from the uniform continent-wide stress field with compression oriented east-northeast. No plane that might represent the rift faults is clearly identifiable, however, from the seismicity pattern. Some of the earthquakes seem to be on small northwest trending transverse faults that offset the rift fault system. These authors considered that the impact structure is not the controlling factor in the local seismicity.

Kumarapeli (1987), after a review of the seismotectonics of Eastern Canada, wrote that in the Charlevoix area slip appears to be taking place on approximately NE trending faults "*and therefore slip should be dominantly strike-slip and not reverse as indicated by focal-plane solutions*" (p. 42). He concluded that "*If the earthquakes of Eastern Canada are produced by an approximately ENE directed, horizontal compressive stress, the faulting in the CHV and LSL zones must dominantly be strike-slip (right lateral) and not dominantly reverse as indicated by focal plane solutions*". Note: CHV=Charlevoix, LSL=Lower St. Lawrence.

C- Objectives and Field Work

1- Objectives

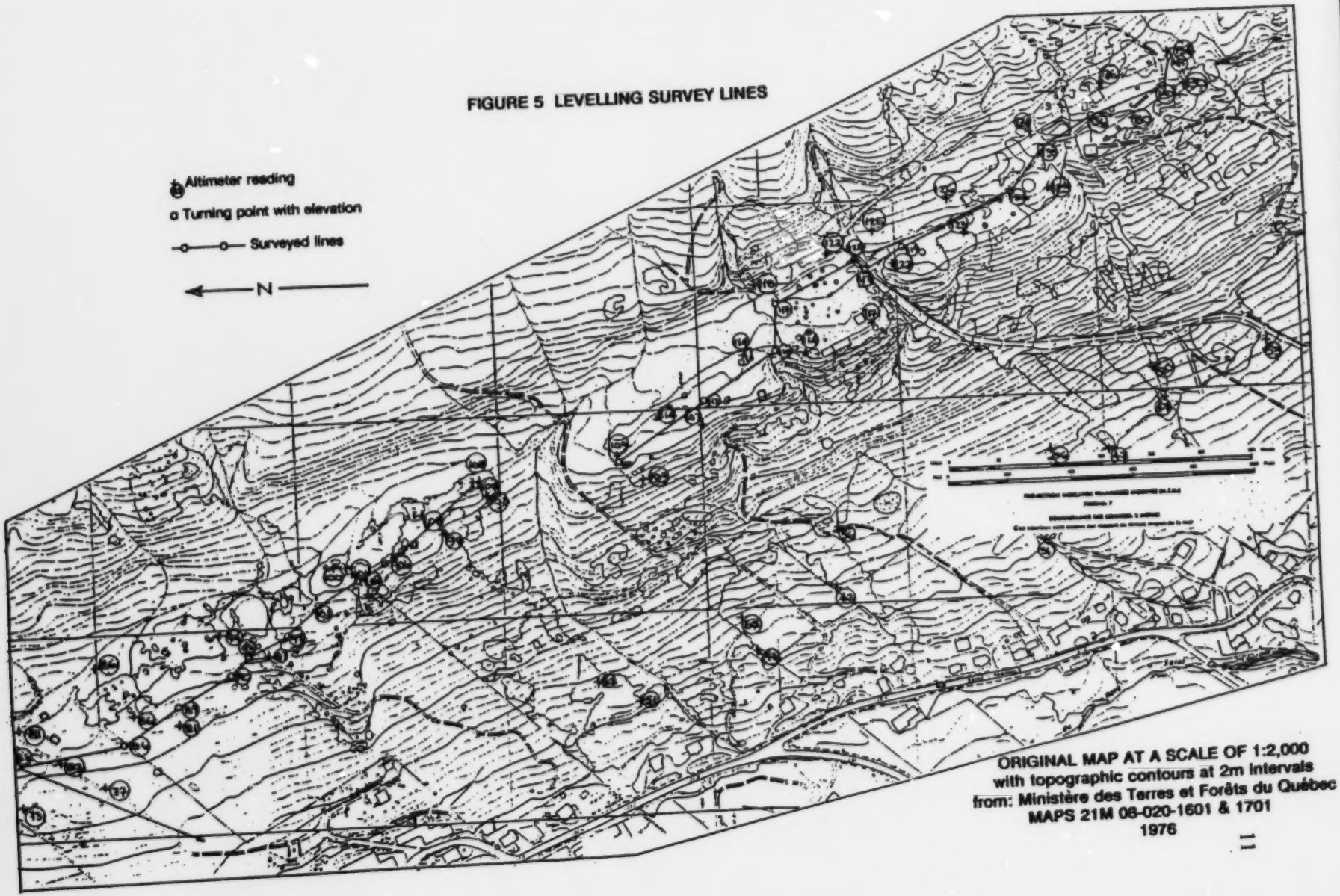
The objectives of the work are the determination of the attitude, elevation and internal character of the terrace in order to ascertain whether or not it was tilted and truly offset.

2- Method of study

a- Levelling

Topographic maps, some at scales as small as 1:500, were evaluated. However the contour interval is too large to enable the precise determination of the elevations at various points on the terrace. None of these maps is recent and human activities have resulted in minor modifications to the topography. It was therefore necessary to run a levelling survey from one end of the terrace to the other in order to determine precise elevations. A preliminary survey, run along a line perpendicular to the trend of the tilted terrace, was made using an electronic altimeter, with a precision of about 1 m. Later, a more precise survey was completed using a precision level, a rod and a surveyor's tape. The altimeter survey was then tied to the level line and the elevations initially established were recalculated. Some of the results of the altimeter survey are erratic and do not agree with the spot elevations shown on the 1:2000 topographic map (Figure 5 - A larger scale version of this map is shown in Annex I).

FIGURE 5 LEVELLING SURVEY LINES



ORIGINAL MAP AT A SCALE OF 1:2,000
with topographic contours at 2m intervals
from: Ministère des Terres et Forêts du Québec
MAPS 21M 08-020-1601 & 1701
1976

Access to the southern segment was relatively easy via roads leading to summer camps on top of the slopes at the level of the terrace. Access to the northern segment was more difficult, being provided by a poorly maintained road not suitable for motor vehicles. The land is privately owned, therefore trees and other vegetation could not be removed. This prevented running a continuous line across the two segments, thus separate surveys were run on each segment and the results were linked to a common reference point of known elevation further down in the valley. Also for the same reasons, the lines were anything but straight as they had to go around obstacles (Figure 5).

b- Georadar

Ground-probing radar or "Georadar" is a high-resolution sounding technique which is efficient both in soils and bedrock. It can resolve features a few centimetres thick with depth accuracies of a few tens of centimeters (Davis and Annan, 1986). Depths up to 30 meters can be investigated in sand, gravel, rock and water. The instrument used for this work is a "pulseEKKO IV" made in Canada by Sensors & Software (formerly A-Cubed Inc.) which is supplied with proprietary data collecting and processing software.

The principles of georadar are similar to those of seismic reflection techniques. The radar produces a short pulse of high frequency electromagnetic energy (10 - 1000 MHz) which is transmitted and propagates in the ground according to the high frequency electrical properties of the material which depend mainly on water content. The radar signal is reflected when it encounters a change in electrical properties (i.e. relative dielectric permittivity). Changes in electrical properties do not depend only on the presence of water and dry material can yield reflections if material of contrasting electric properties is present (i.e. dielectric constant, conductivity & magnetic permeability). The reflected signal is picked up by a receiver which amplifies it and transforms it so that it can be displayed. The radar system transmits and receives signals many thousand of times per second so that a survey is quite rapid.

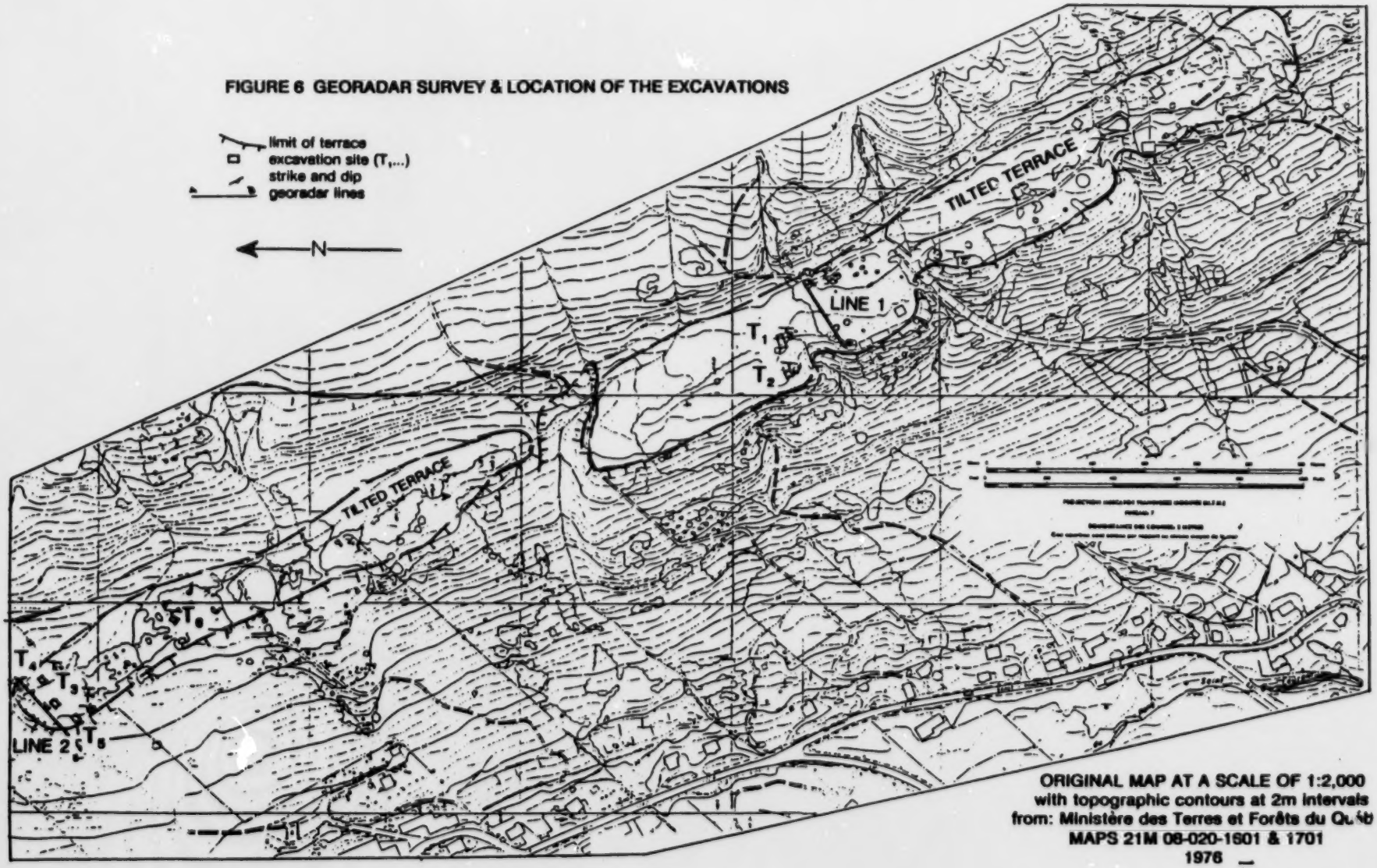
The data are in digital form and can be stored on magnetic support (computer disk) to be processed later. The parameters can be varied so as to optimize resolution, enhance steeply dipping and horizontal layers, increase the depth of investigation, etc.

The survey mode used for this study was the reflection mode (common offset method) which is frequently used to map soil stratigraphy. The instrument was operated in a step mode where readings along a line are taken singly at a determined interval. Before proceeding the system parameter settings are selected (start position, step size, antenna separation, survey mode, gain, window width, attenuation, velocity, antenna frequency, distance units, pulser voltage, etc..). The data are then collected and plotted on the screen of the system computer for further adjustments. A separate software module allows the data to be presented using different parameter settings with the addition of filtering, spreading and exponential compensation, topographic corrections, etc. One limit of the method is that a constant and unique velocity has to be assigned to the soil even if many different horizons with different velocities are present. This can introduce distortion in the record which is produced. Further details on the operating principles and modes of ground-probing radar are found in Davis and Annan (1989).

c- Trenching

Trenches were excavated on each segment of the terrace in a direction perpendicular to the length of the terrace. The georadar survey lines across the width of each segment previous to the excavation were also the most favorable sites for excavating. It was believed that a trench should be dug as close as feasible to the eastern limit of each segment in order to intersect all the different underlying stratigraphic horizons and another at the outside limit of the terrace, on the western side, in order to verify the continuity of the subsurface horizons. The location of the trenches is shown on Figure 6 (a large scale version is in Appendix I). On the southern segment a good access road up the relatively steep slope allowed the use of a backhoe with a bucket excavator. Two trenches were dug on this segment along a line perpendicular to the length of the terrace, one near each end of the section. The

FIGURE 6 GEORADAR SURVEY & LOCATION OF THE EXCAVATIONS



trench at the eastern end (T_1) was five meters long, two meters wide and 4 meters deep. The elevation of the surface there was 113 meters. The trench at the western side of the terrace (T_2) was three meters long, two meters wide and two meters deep with a surface elevation of 109 meters.

There was no possibility of digging a continuous trench across the width of the terrace because of the presence of trees. Permission had to be obtained from the property owner who allowed the excavation of trenches or pits as long as no visible marks were left after backfilling of the holes. We even signed a written agreement stating that we would leave the site in the condition it was in before we began the work. This prevented any tampering with the vegetation and also meant that we had to stay away from houses or any other type of buildings.

The depth of excavation was limited by the length of the arm of the backhoe and also by the non-cohesive nature and the relatively low water content of the granular material which tended to slump back into the trench as it became deeper. The water table which usually limits the depth which can be attained in excavations in sand was of no concern here. It was not observed in any of the excavations.

Access to the northern segment was limited to off-road vehicles able to climb a steep slope and it was not possible to bring heavy machinery there. Digging had to be done with hand shovels. Small pits were dug at four different locations, usually near minor scarps which increased the height of the sections observed. A larger trench, 1.5 meter deep and three meters long, was dug perpendicular to the length of the segment at a location near the middle of the width of the terrace (T_3 on Figures 6 and 13). The elevation of the ground surface was 82 meters. The trench was dug without any wall support and this imposed a limit on the depth attained. The dry sand tended to flow back into the trench along an angle of about 35°, thus widening it and increasing the amount of material to be moved. It was not practical and safe to attempt to dig any deeper.

The structure of the material near the surface in all trenches was readily visible being underlined by thin ilmenite-rich dark layers.

PHOTOGRAPH 1

THE TILTED TERRACE (indicated by the arrow). The village of Baie St. Paul is seen in the midground.

II- THE TILTED TERRACE

A- Description

Very little has been written about the tilted terrace located on the eastern side of the Rivière Du Gouffre valley near Baie St. Paul. Chagnon (1969) described it and reported a personal communication from A. Mailloux, a pedologist, about an eolian origin for the slope which would result from erosion and transport to the south by the dominant winds from the north. Mailloux claimed to have observed poli hed and faceted pebbles at the surface of the terrace. Rondot (1989) showed the northernmost part of the inclined terrace on his detailed map of the area, but did not comment upon it (Figure 4).

The terrace is located near the top of the valley slope and shows an obvious inclination to the north when seen from a viewpoint located at a comparable elevation across the valley (Photograph 1). The terrace appears to be separated into two unequal segments which are neither aligned horizontally nor vertically. The lateral offset is best observed on air photographs and on small-scale topographic maps whereas the horizontal offset is easily observed from across the valley.

1- Levelling

Terrace elevation decrease from 141 m at the southern end of the southern segment to 81 m at the northern end of the northern segment. The elevation at the adjacent ends of the two segments is 110 m. There is no appreciable vertical displacement of the terrace where it is cut by the entrenched stream, and the slope is relatively uniform over the whole length (1256 m), being on the order of 3.21 degrees to the north for the northern segment and 2.1 degrees to the north for the southern segment. Vertical displacement has to be less than one meter even though it appears to be more when viewed from across the valley.

A terrace in marine clay at a lower level, has elevations of 32 m at the southern extremity and of 67 m at the northern extremity thus showing a slope towards the St. Lawrence River, opposite that of the upper terrace. It is not as long as the upper terrace and it does not extend as far as the stream which bisects the upper terrace.

2- Georadar

The georadar survey was run along two lines perpendicular to the length of each segment of the terrace (Figure 6). The purpose of this survey was to obtain as much information as possible on the nature and geometry of the soil horizons below the surface of the terrace. This information was necessary for the selection of the excavation sites.

The georadar lines were sited mainly on ease of access and availability of a corridor free of vegetation. Areas where a complete section across the terrace could be completed were selected. Line 1, on the southern segment, is located at the widest part of the terrace and it covers most of the width, beginning at the foot of the slope against which the terrace rests and ending almost at the steep slope at its western limit. Line 1 was run from east to west and then back using different parameter settings. Line 2, on the northern segment is located almost at the northern limit. This site was selected because the surface of the terrace is relatively uniform and free of obstacles. The terrace is separated from the upper eastern slope of the valley by a stream and its surface is inclined to the east and to the west (Figure 13). This gives a convex profile which is more pronounced to the south where the surface of the terrace is also highly irregular.

The processed but uninterpreted georadar data for the two lines are presented on Figures 7, 8, 9 and 10. The parameter settings and the signal processing parameters for each record are shown on the tables (1 to 4) next to each figure. The propagation velocity used was selected on a table of characteristic velocities for specific types of soils supplied with the software. The results of the interpretation of Figures 9 and 10 are shown on Figures 11 and 12.

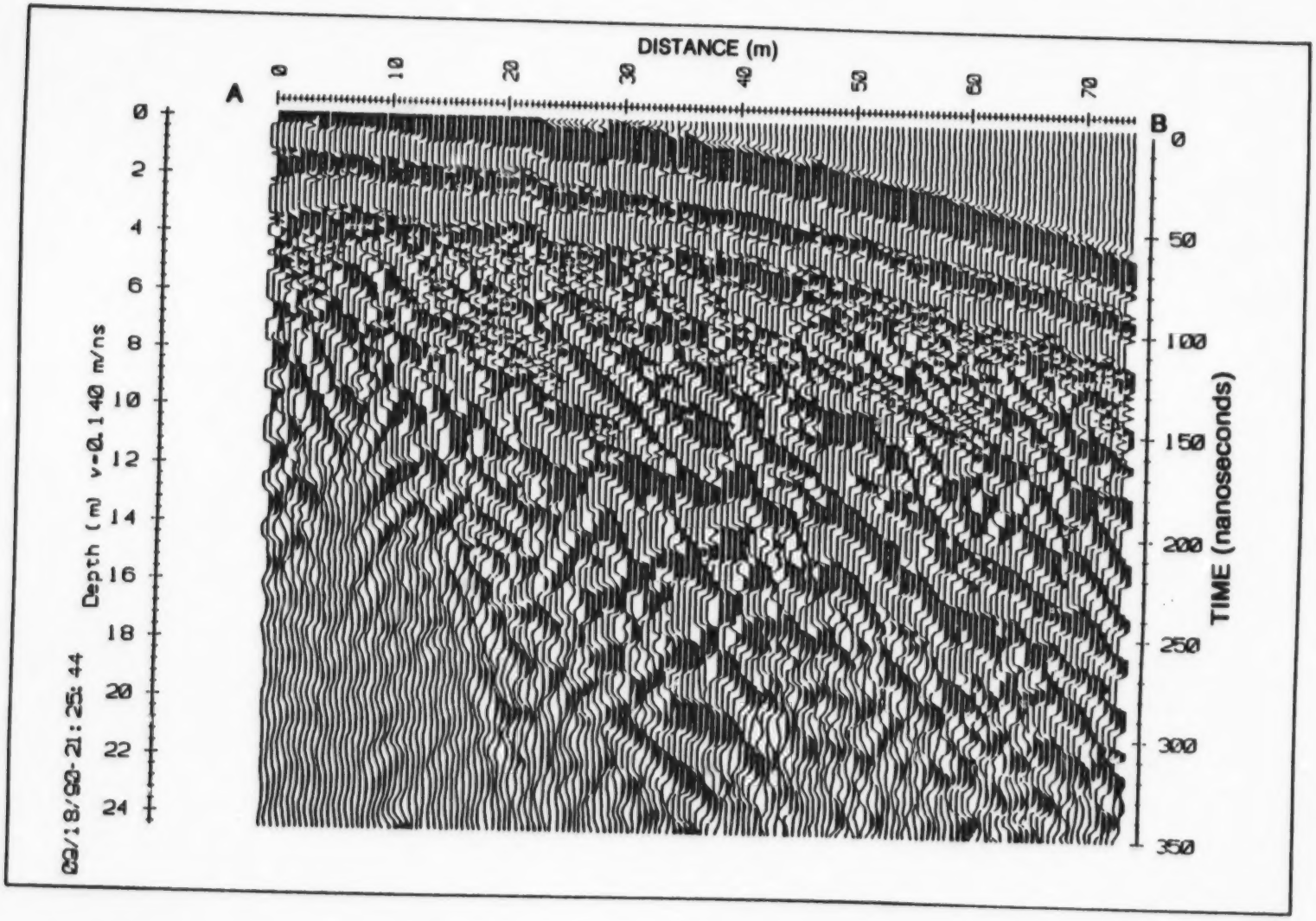


FIGURE 7 GEORADAR SURVEY - LINE 1 (A-B) - V/H = 4

WITHOUT INTERPRETATION

```
DATA FILE #1 PARAMETERS:
   Data File  = c:\peiv\BSP1ed.hd
   1
   Terrasse inclinee Baie St-Paul - 50 MHz
   Section perpendiculaire (est-ouest)
   04/06/90
   NUMBER OF TRACES    = 149
   NUMBER OF PTS/TRC   = 640
   TIMEZERO AT POINT   = 62
   TOTAL TIME WINDOW   = 1024
   STARTING POSITION   = 0.000000
   FINAL POSITION      = 74.000000
   STEP SIZE USED      = 0.500000
   POSITION UNITS      = metres
   NOMINAL FREQUENCY   = 50.000000
   ANTENNA SEPARATION  = 1.000000
   PULSER VOLTAGE (V)  = 1000
   NUMBER OF STACKS    = 256
   SURVEY MODE         = Reflection
   SOURCE DATA FILE    = a:\BSTPAUL1
   DELETED POSITIONS 9.500000 TO 9.500000
   DELETED POSITIONS 10.500000 TO 10.500000
   DELETED POSITIONS 13.500000 TO 13.500000
   TIMEZERO DRIFT CORRECTION APPLIED
   SIGNAL SATURATION CORRECTION APPLIED
   ELEVATION DATA ENTERED : MAX = 3.800000   MIN = 0.074286

PROCESSING SELECTED:
   Trace Stacking     : 3
   Points Stacking    : 1
   Trace Differencing: N
   Gain Type   : CONSTANT
     Factor    : 50.000
   Selection   : Time = -2 to 350  ns
                 Trace = 1 to 149
   Picture Id : 09/18/90-21:25:44

PLOT LAYOUT PARAMETERS:
   Trace Spacing      : 0.045"
   Trace Width        : 0.090"
   Trace Position     : 1.000" to 6.500"
   Left/Right Margin : 0.500" / 0.500"
   Border Size        : 0.500"
   Page Length/Width : 0.000" / 8.500"
   Printer Name       : Epson LQ-2550 360x180
```

TABLE 1 - PARAMETER SETTINGS FOR LINE 1 (A-B)

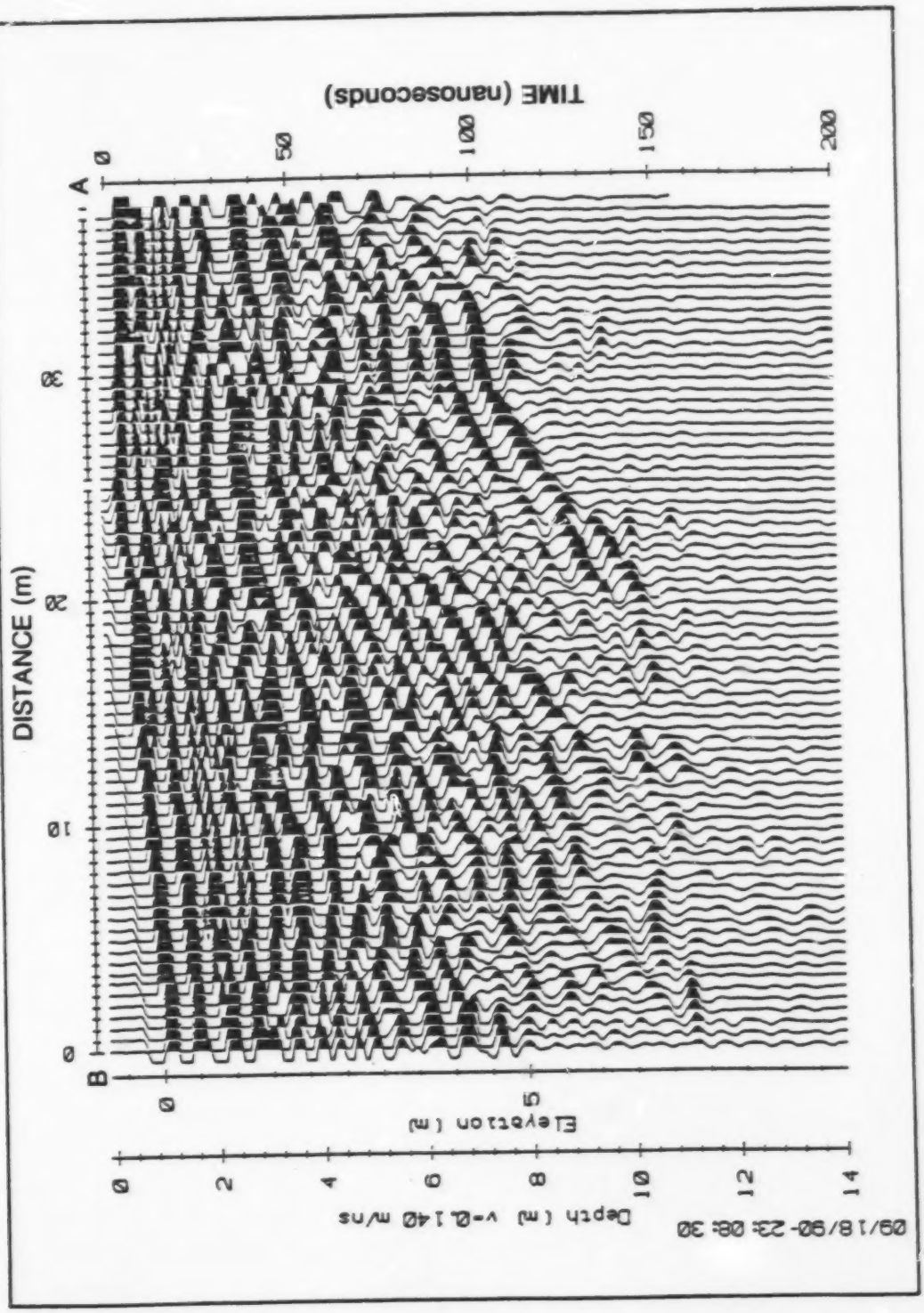


FIGURE 8 GEORADAR SURVEY - LINE 1 (B-A) - V/H = 4
WITHOUT INTERPRETATION

```
PulseEKKO IV Data Sheet

DATA FILE #1 PARAMETERS:
   Data File  = c:\peiv\bsp2ed.hd
   1
   Terrasse inclinee Baie St-Paul - 200 MHz
   Section perpendiculaire (ouest-est)
   04/06/90
   NUMBER OF TRACES   = 51
   NUMBER OF PTS/TRC  = 640
   TIMEZERO AT POINT  = 126
   TOTAL TIME WINDOW  = 512
   STARTING POSITION  = 0.000000
   FINAL POSITION     = 25.000000
   STEP SIZE USED     = 0.500000
   POSITION UNITS     = metres
   NOMINAL FREQUENCY  = 200.000000
   ANTENNA SEPARATION = 1.000000
   PULSER VOLTAGE (V) = 400
   NUMBER OF STACKS   = 256
   SURVEY MODE        = Reflection
   SOURCE DATA FILE   = a:\BSTPAUL2
   TIMEZERO DRIFT CORRECTION APPLIED
   SIGNAL SATURATION CORRECTION APPLIED
   ELEVATION DATA ENTERED : MAX = 0.575000   MIN = 0.000000

DATA FILE #2 PARAMETERS:
   Data File  = c:\peiv\BST3ed.hd
   1
   Terrasse inclinee Baie St-Paul - 200 MHz
   Section perpendiculaire (ouest-est)
   04/06/90
   NUMBER OF TRACES   = 25
   NUMBER OF PTS/TRC  = 640
   TIMEZERO AT POINT  = 126
   TOTAL TIME WINDOW  = 512
   STARTING POSITION  = 25.000000
   FINAL POSITION     = 37.000000
   STEP SIZE USED     = 0.500000
   POSITION UNITS     = metres
   NOMINAL FREQUENCY  = 200.000000
   ANTENNA SEPARATION = 1.000000
   PULSER VOLTAGE (V) = 400
   NUMBER OF STACKS   = 256
   SURVEY MODE        = Reflection
   SOURCE DATA FILE   = a:\BSTPAUL3
   TIMEZERO DRIFT CORRECTION APPLIED
   SIGNAL SATURATION CORRECTION APPLIED
   SOURCE DATA FILE   = C:\PEIV\BSP3ED
   TIMEZERO DRIFT CORRECTION APPLIED
   ELEVATION DATA ENTERED : MAX = 0.600000   MIN = 0.000000

DATA FILE #3 PARAMETERS:
   Data File  = c:\peiv\BSP4ed.hd
   1
   Terrasse inclinee Baie St-Paul - 200 MHz
   Section perpendiculaire (ouest-est)
   05/06/90
   NUMBER OF TRACES   = 26
   NUMBER OF PTS/TRC  = 320
   TIMEZERO AT POINT  = 126
   TOTAL TIME WINDOW  = 256
   STARTING POSITION  = 25.000000
   FINAL POSITION     = 37.500000
   STEP SIZE USED     = 0.500000
   POSITION UNITS     = metres
   NOMINAL FREQUENCY  = 200.000000
   ANTENNA SEPARATION = 1.000000
   PULSER VOLTAGE (V) = 400
   NUMBER OF STACKS   = 256
   SURVEY MODE        = Reflection
   SOURCE DATA FILE   = a:\BSTPAUL4
   TIMEZERO DRIFT CORRECTION APPLIED
   SIGNAL SATURATION CORRECTION APPLIED
   TIMEZERO DRIFT CORRECTION APPLIED
   ELEVATION DATA ENTERED : MAX = 0.600000   MIN = 0.000000

PROCESSING SELECTED:
   Trace Stacking    : 3
   Points Stacking   : 1
   Trace Differencing: N
   Gain Type   : CONSTANT
     Factor    : 50.000
   Selection   : Time = -2 to 200  ns
                 Trace = 1 to 51
   Picture Id : 09/18/90-23:08:30

FILE MERGING :
    1 - c:\peiv\bsp2ed
    2 - c:\peiv\BST3ed
    3 - c:\peiv\BSP4ed

PLOT LAYOUT PARAMETERS:
   Trace Spacing      : 0.085"
   Trace Width        : 0.170"
   Trace Position     : 1.000" to 8.500"
   Left/Right Margin  : 0.500" / 0.500"
   Border Size        : 0.500"
   Page Length/Width  : 0.000" / 8.500"
   Printer Name       : Epson LQ-2550 360x180
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TABLE 2 - PARAMETER SETTINGS FOR LINE 1 (B-A)

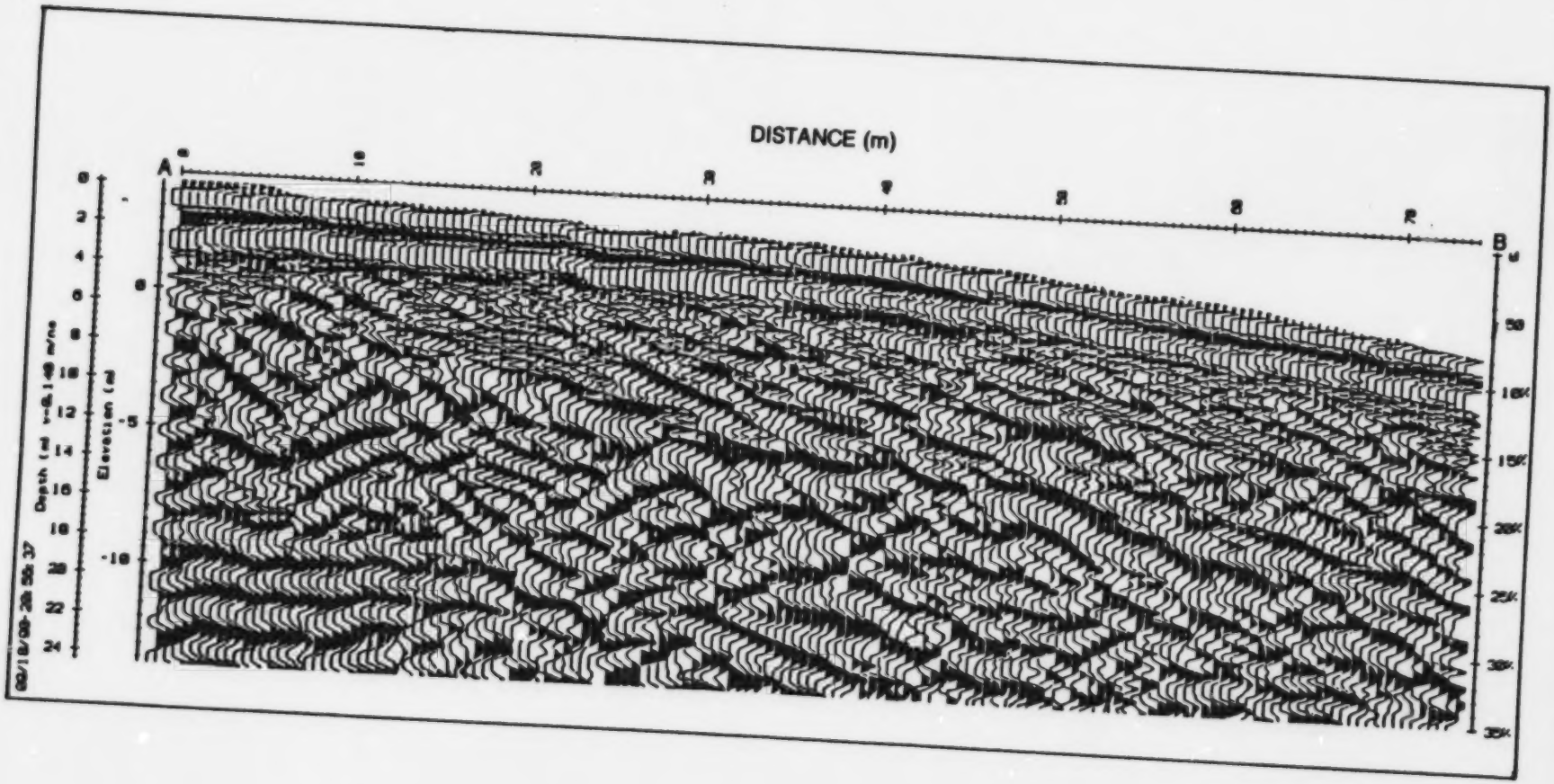


FIGURE 9 GEORADAR SURVEY - LINE 1 (A-B) - V/H = 0.85
WITHOUT INTERPRETATION

```
PulseEKKO IV Data Sheet

DATA FILE #1 PARAMETERS:
   Data File  = c:\peiv\BSP1ed.hd
   1
   Terrasse inclinee Baie St-Paul - 50 MHz
   Section perpendiculaire (est-ouest)
   04/06/90
   NUMBER OF TRACES    = 149
   NUMBER OF PTS/TRC   = 640
   TIMEZERO AT POINT   = 62
   TOTAL TIME WINDOW   = 1024
   STARTING POSITION   = 0.000000
   FINAL POSITION      = 74.000000
   STEP SIZE USED      = 0.500000
   POSITION UNITS      = metres
   NOMINAL FREQUENCY   = 50.000000
   ANTENNA SEPARATION  = 1.000000
   PULSER VOLTAGE (V)  = 1000
   NUMBER OF STACKS    = 256
   SURVEY MODE         = Reflection
   SOURCE DATA FILE    = a:\BSTPAUL1
   DELETED POSITIONS 9.500000 TO 9.500000
   DELETED POSITIONS 10.500000 TO 10.500000
   DELETED POSITIONS 13.500000 TO 13.500000
   TIMEZERO DRIFT CORRECTION APPLIED
   SIGNAL SATURATION CORRECTION APPLIED
   ELEVATION DATA ENTERED : MAX = 3.800000   MIN = 0.074286

PROCESSING SELECTED:
   Trace Stacking     : 3
   Points Stacking    : 1
   Trace Differencing: N
   Gain Type    : AGC
     Window     : 1.000  pulse widths
     Amount     : 0.500  of full window
     Region     : 1 to 47 points
   Selection    : Time = -2 to 350  ns
                  Trace = 1 to 149
   Picture Id : 09/18/90-20:56:37

PLOT LAYOUT PARAMETERS:
   Trace Spacing       : 0.100"
   Trace Width         : 0.200"
   Trace Position      : 1.000" to 6.500"
   Left/Right Margin : 0.500" / 0.500"
   Border Size         : 0.500"
   Page Length/Width : 0.000" / 8.500"
   Printer Name        : Epson LQ-2550 360x180
```

TABLE 3 - PARAMETER SETTINGS FOR LINE 1 (A-B)

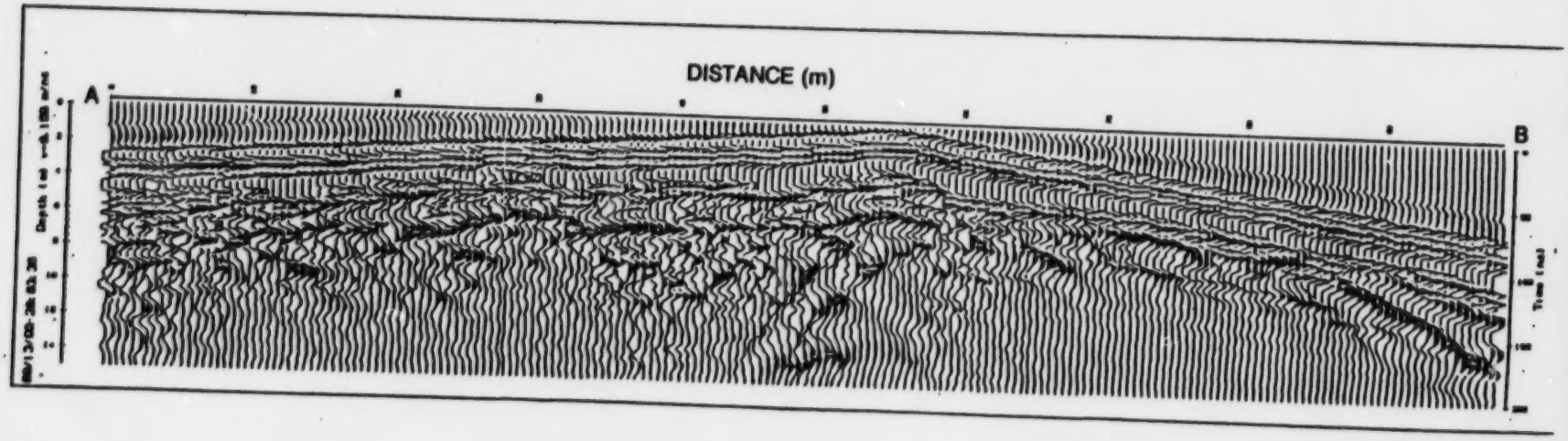


FIGURE 10 GEORADAR SURVEY - LINE 2 (A-B) - V/H = 0.8
WITHOUT INTERPRETATION

```
PulseEKKO IV Data Sheet

DATA FILE #1 PARAMETERS:
   Data File  = C:\PEIV\BSTP6R.hd
   2
   Terrasse inclinee Baie St-Paul - 50 MHz
   Section perpendiculaire (est-ouest)
   10/09/90
   NUMBER OF TRACES    = 197
   NUMBER OF PTS/TRC   = 640
   TIMEZERO AT POINT   = 48
   TOTAL TIME WINDOW   = 1024
   STARTING POSITION   = 0.000000
   FINAL POSITION      = 98.000000
   STEP SIZE USED      = 0.500000
   POSITION UNITS      = metres
   NOMINAL FREQUENCY   = 50.000000
   ANTENNA SEPARATION  = 1.000000
   PULSER VOLTAGE (V)  = 1000
   NUMBER OF STACKS    = 256
   SURVEY MODE         = Reflection
   SOURCE DATA FILE    = a:\BSTPAUL6
   TIMEZERO DRIFT CORRECTION APPLIED
   SIGNAL SATURATION CORRECTION APPLIED
   ELEVATION DATA ENTERED : MAX = 3.400000   MIN = 0.000000

PROCESSING SELECTED:
   Trace Stacking     : 4
   Points Stacking    : 1
   Trace Differencing: N
   Gain Type   : AGC
     Window    : 1.000  pulse widths
     Amount    : 0.050  of full window
     Region    : 1 to 33 points
   Selection   : Time = -1 to 200  ns
                 Trace = 1 to 197
   Picture Id  : 09/13/90-20:03:36

PLOT LAYOUT PARAMETERS:
   Trace Spacing       : 0.150"
   Trace Width         : 0.300"
   Trace Position      : 1.000" to 6.500"
   Left/Right Margin   : 0.500" / 0.500"
   Border Size         : 0.500"
   Page Length/Width   : 11.000" / 8.500"
   Printer Name        : Epson LQ-2550 360x180
```

TABLE 4 - PARAMETER SETTINGS FOR LINE 2 (A-B)

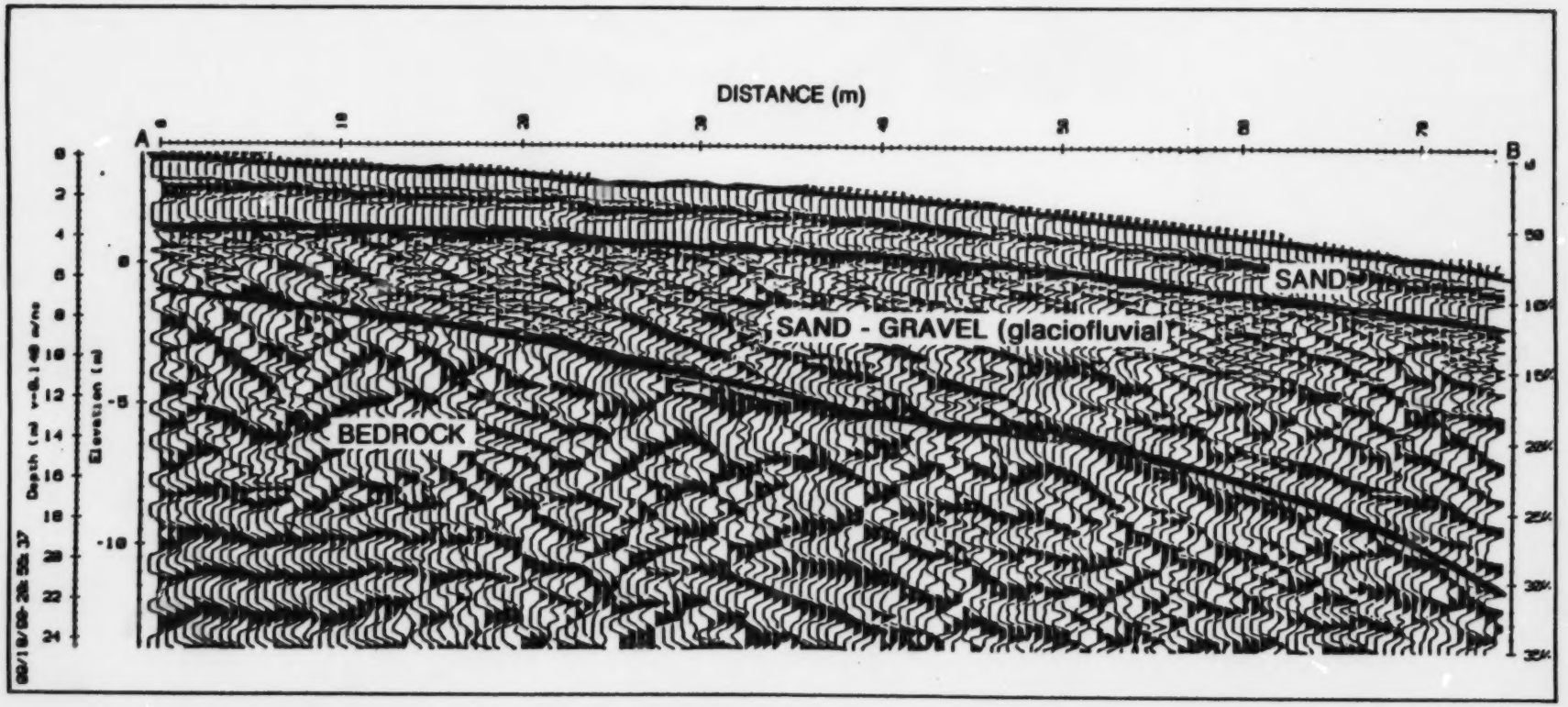


FIGURE 11 DIRECT INTERPRETATION - LINE 1 (A-B)

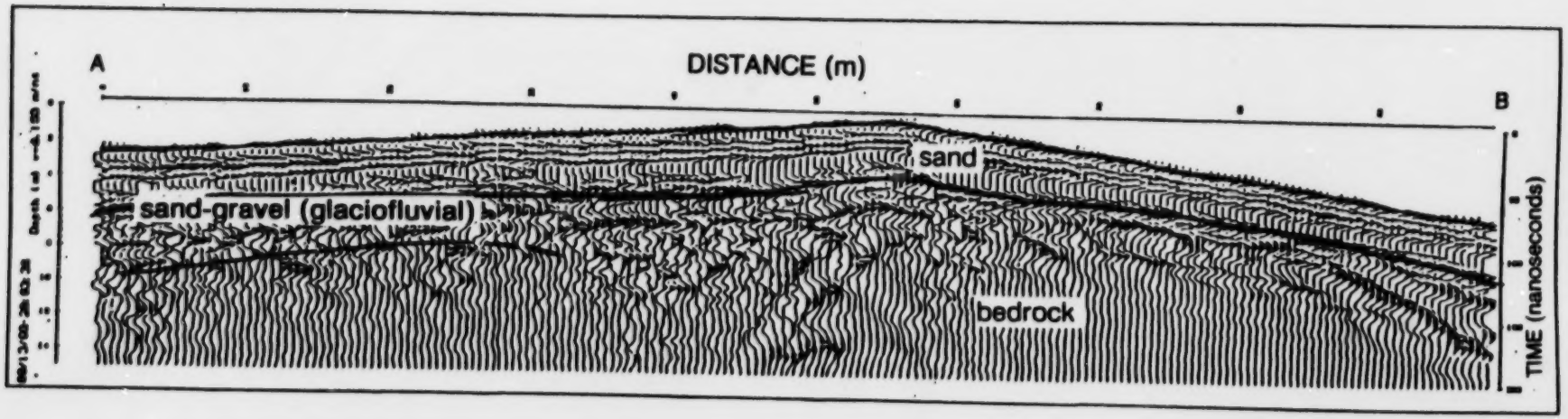


FIGURE 12 DIRECT INTERPRETATION - LINE 2 (A-B)

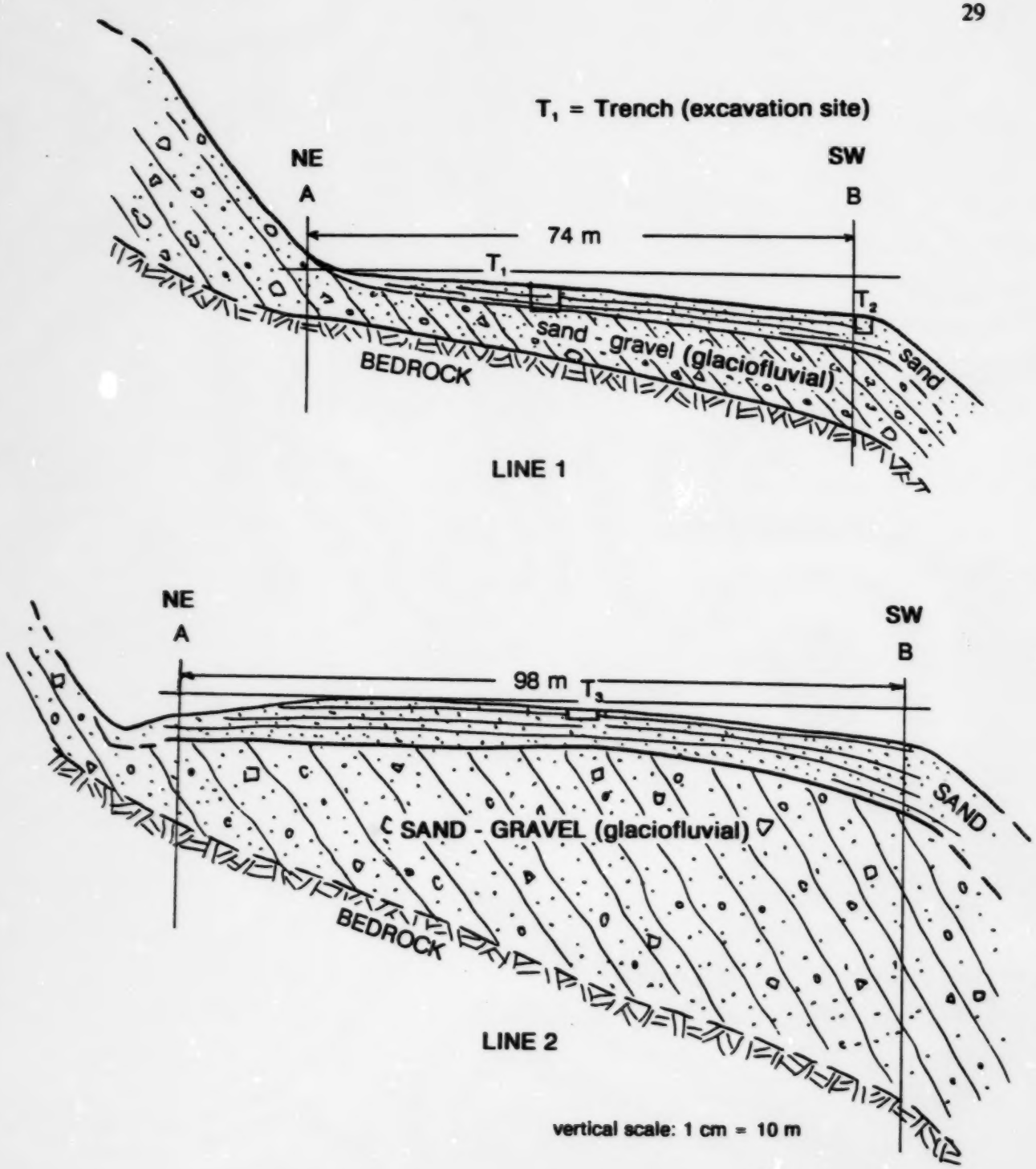


FIGURE 13 FINAL INTERPRETATION - GEORADAR SURVEY LINES

On line 1 three different layers can be distinguished. A nearly horizontal layer at the surface and 4 meters thick at B overlies a gently dipping layer of material which rests on the bedrock and varies in thickness from 3 meters at A to 10 meters at B. Three records are shown for this line. Figure 7 shows a record run with 50 MHz antennaes. The vertical to horizontal scale ratio is about 4. This ratio distorts the record on which the various stratigraphic units are visible and the inclination of the layers in increased. The contact between the sand layer and the underlying glaciofluvial material (visible on the surface at a higher elevation at the eastern edge of the terrace) is sharp. The contact between the glaciofluvial material and the bedrock is not as well defined, but is still fairly obvious. This is a record enhanced for resolution at depth and for outlining dipping layers. Figure 8 is a record of line 1 run from B to A (reverse direction) using 200 MHz antennaes and different parameter settings selected in order to emphasize resolution and horizontal layers (Table 2). Relatively continuous thin alternating layers, which were not evident on Figure 7, are now visible just below the surface of the ground. The bedrock is not too obvious on this record. The subsequent excavation near this line showed that the thin bands are reflections from alternating, dark, ilmenite-rich layers which overlie glaciofluvial granular material dipping 30° to the west. There is total agreement between the interpretation of the Line 1 records and the observations and measurements in the excavations. Figure 9 is a record of the same line and data, but with a vertical to horizontal ratio of 0.85 and different parameter settings. The lower ratio eliminates the distortion observed in Figure 7. The horizontal layers are enhanced while the dipping layers are less evident. Figure 11 is a direct interpretation of Figure 9.

Line 2, on the northern segment, is 98 meters in length, which is longer than line 1, and is difficult to represent with a high vertical to horizontal scale ratio because of the excessive distortion (Figure 13). Instead of compressing the horizontal scale, the record was reduced in size as shown in Figure 10. This record is similar to those of Line 1 (Figure 7 and 9), but the inclined layers of the fluvioglacial material and the bedrock are less obvious. Figure 12 shows an interpretation of this record.

Figure 13 is a final interpretation of both lines using georadar data with the observations at the surface and in the excavations (which are projected on the lines).

The results were obtained in dry, or relatively dry, granular sediments located well above the water table. The role of the water content in the generation of reflections, because of discontinuities in relative dielectric permittivity cannot be as great here as in wet material. The alternating ilmenite-rich layers with sandy layers will however give rise to reflections because of the contrast in dielectric constants and magnetic permeability as will the contact between the underlying stratigraphic units.

B- Implications

1- Discussion by previous authors

Terraces have been used as indicators of neotectonic activity in many countries. In some tectonic settings the variations in terrace levels result from vertical uplifting associated with seismic activity. Matsuda (1982) has established relations between the minimum size of an earthquake that can produce crustal deformations such as uplift. The shallower the focal depth, the smaller the earthquake which produces crustal deformation. In Japan earthquakes of magnitude less than 6.0 usually leave no evidence of crustal deformation. Matsuda (1982) wrote that terraces are the result of a sudden uplifting of the ground relative to its former position and that the uplift is usually triggered by causes which are unrelated to crustal movement (i.e. a drop in sea level) but that earthquakes can be triggered by forces which uplift the land, producing terraces. Furthermore the terraces can be tilted by subsequent earthquakes. According to Matsuda (1982) the rate of uplift or of tilting can even be used to predict future events.

Brown and Reilinger (1986) cited numerous cases where vertical deformations have been associated with intraplate earthquakes. Coseismic movements varying from 10 cm to 6 m have been observed. Dating the various terrace levels provides a way of estimating the

average rate of uplift and sometimes the age of the seismic events themselves (Ota, 1986). Coseismic marine strandlines are common in Japan where they have been described by numerous authors (e.g. Matsuda et al., 1978 - Shimazaki and Nakata, 1980). Nakata et al. (1980) established direct relationships between terrace levels and specific seismic events. Plafker (1987) discussed, in great detail, the application of marine-terrace data to paleoseismic studies. Most of the applications are from subduction zones.

McCalpin (1987) described various geologic criteria for recognizing paleoseismic events some of which are related to displacement of terraces. However, in areas where glacial unloading and eustatic sea-level movements occur, as in Eastern Canada, simple and direct relations between uplift and paleoseismicity are not easily established.

Tilting of terraces towards the land has also been interpreted as evidence of coseismic compression in subduction zones (Ota, 1986). Tamura (1979) reported tilting of recent marine terraces on Sado island in central Japan resulting from differential uplift. Warping of alluvial terraces in a valley was also considered as evidence of deformation (Schumm, 1986). In cases where terraces are subjected to repeated movements, the oldest would be the most deformed by uplift (convex) or subsidence (concave) and would show the greatest offset by faulting (Machida, 1960).

2- Interpretation

a- Stratigraphy of the southern segment

Two trenches were dug on the southern segment (trenches T_1 and T_2). Trench T_1 was excavated at an elevation of 113 meters down to an elevation of 109 meters. At the surface a thin (0.02m) organic rich layer of sandy material overlies alternating medium to coarse sand and dark ilmenite-rich layers. The sand layers are planar, parallel with little evidence of discontinuity, show no ripples, cross laminations and graded bedding and no evidence of biological action. When beds are discontinuous the termination usually results from convergence or lateral gradation of the composition. Near the bottom of the trench the sand

layers overlie dark grey fluvioglacial material (reworked till) made up of particles ranging from fine to very coarse. This material is dipping 30° towards the valley.

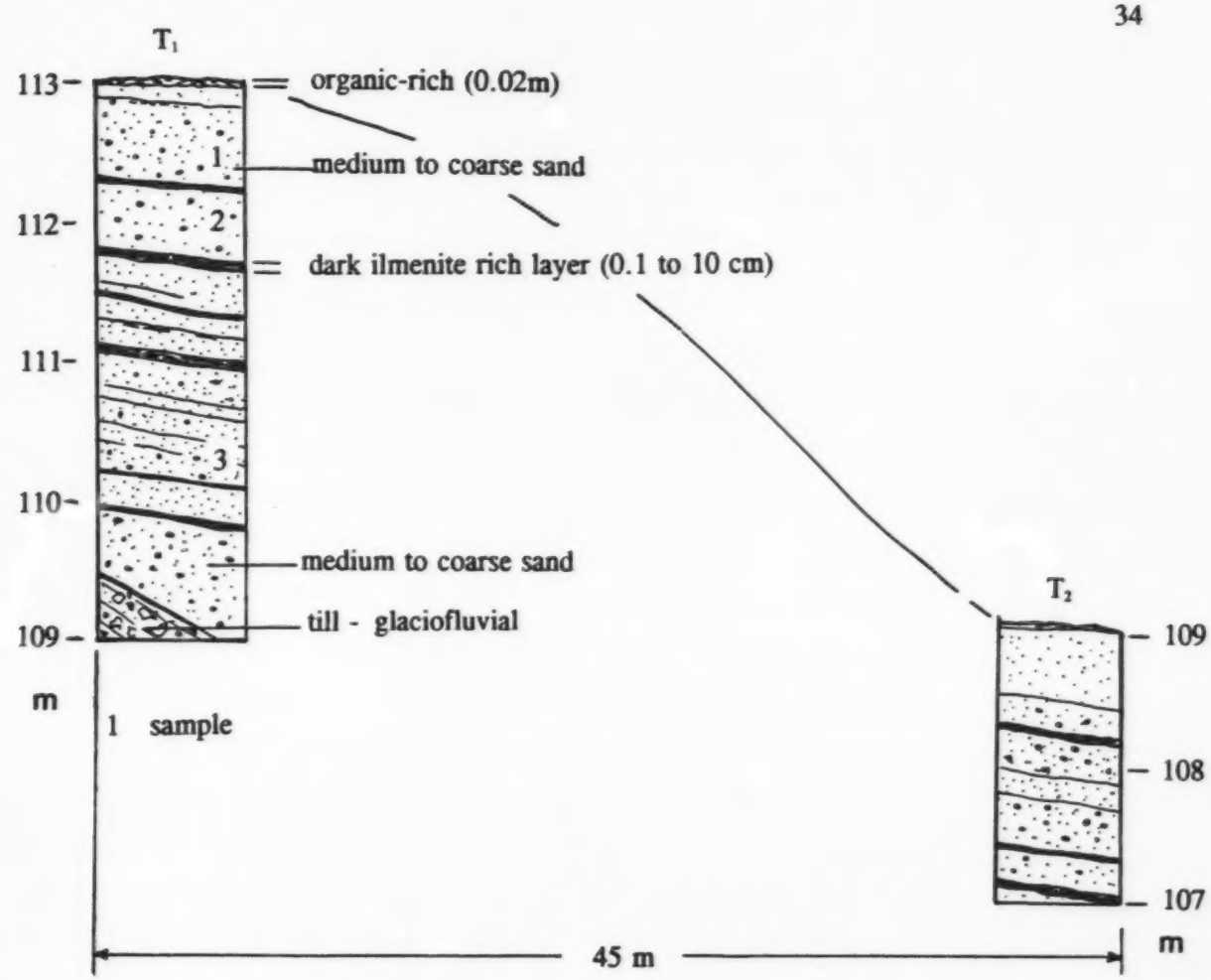
The clean sand layers are from 0.02 m to 0.2 m in thickness and the dark ilmenite-rich layers are from 0.001 to 0.10 m in thickness. Figure 14a shows the stratigraphic sequence as observed on the southern wall of the trench. Photograph 2 shows the same wall. Three samples were taken at depths of 0.7 m, 1m and 3-4 m. Granulometric analysis of each sample was performed with sieves and the samples were examined with a stereomicroscope.

Sample 1 is a medium sand with an effective diameter of 0.2 mm and a uniformity coefficient (Hazen coefficient) of 1.85. This is a well-sorted uniform sand with a curve typical of beach sand (Figure 15). Microscope examination indicates that 10% of the particles are angular, 35% are subangular and 55% are subrounded. Quartz and ilmenite are abundant and 30 to 40% of the ilmenite grains are elongated.

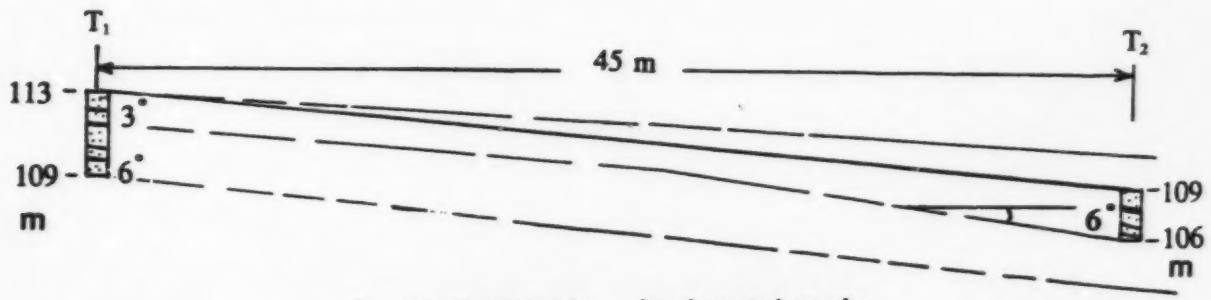
Sample 2 is a medium to coarse sand with an effective diameter of 0.27 mm and a uniformity coefficient of 2.04 (Figure 16), which is barely above the limit for a uniform sand (2.0). Microscope examination shows that 10% are of the particles are angular, 40% subangular and 50% subrounded.

Sample 3 is a medium to coarse sand with an effective diameter of 0.23 mm and a uniformity oefficient of 3.04 (Figure 17), showing a larger spread in diameter than the first two samples which are from higher horizons. Microscope examination shows that 15% of the particles are angular, 40% are subangular and 45% are subrounded.

The three samples have similar grain size distribution and show characteristics typical of beach sand. The two upper samples are well sorted and contain dominant proportions of subrounded particles. The proportion of angular particles increases with depth and the sorting decreases with depth. The layering is also more diffuse at depth and the deeper dark ilmenite-rich layers are thinner and contain less ilmenite.



a - vertical scale = 6X horizontal scale



b - vertical scale = horizontal scale

FIGURE 14 STRATIGRAPHY - SOUTHERN SEGMENT

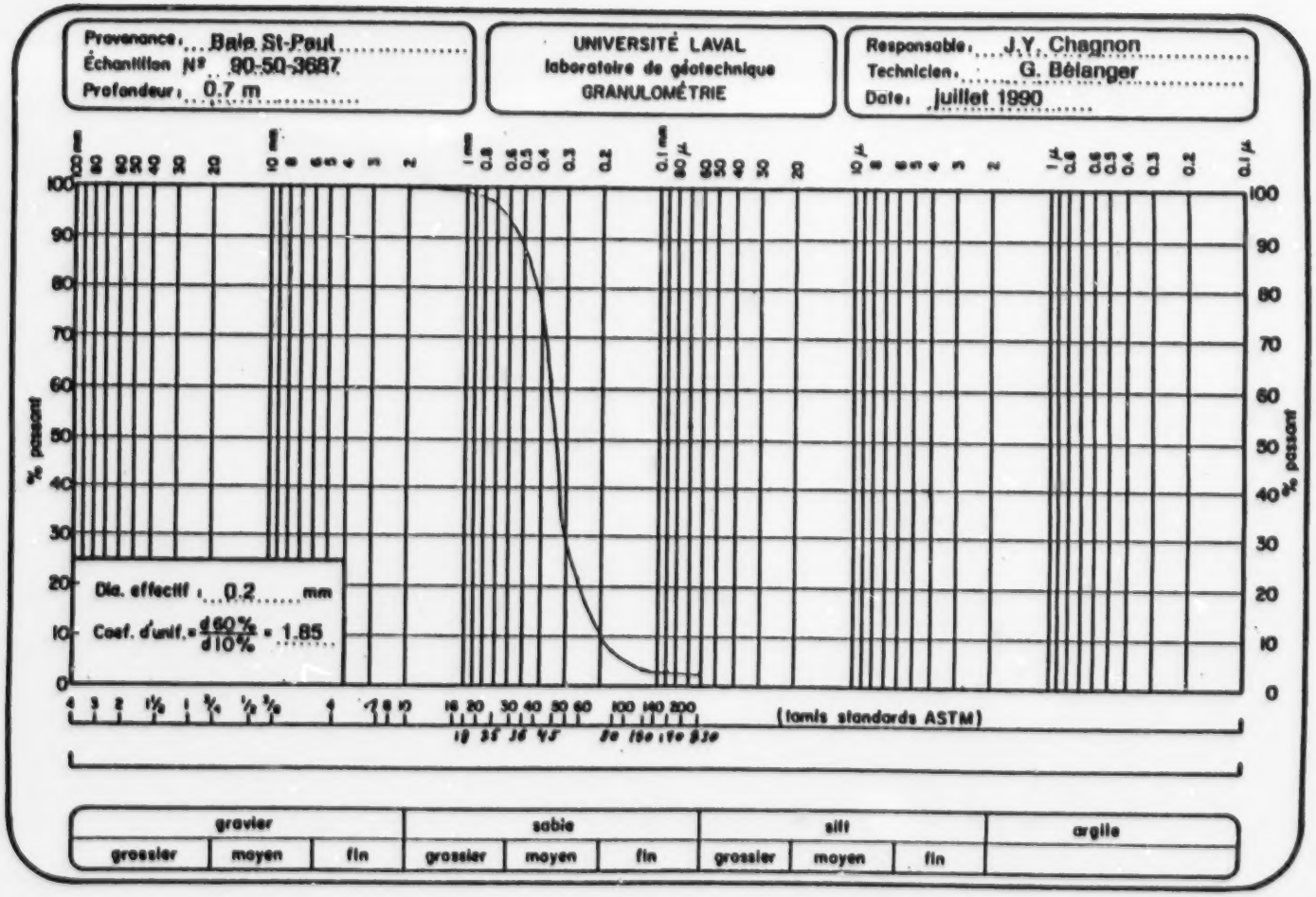


FIGURE 15 GRAIN SIZE ANALYSIS - SAMPLE 1

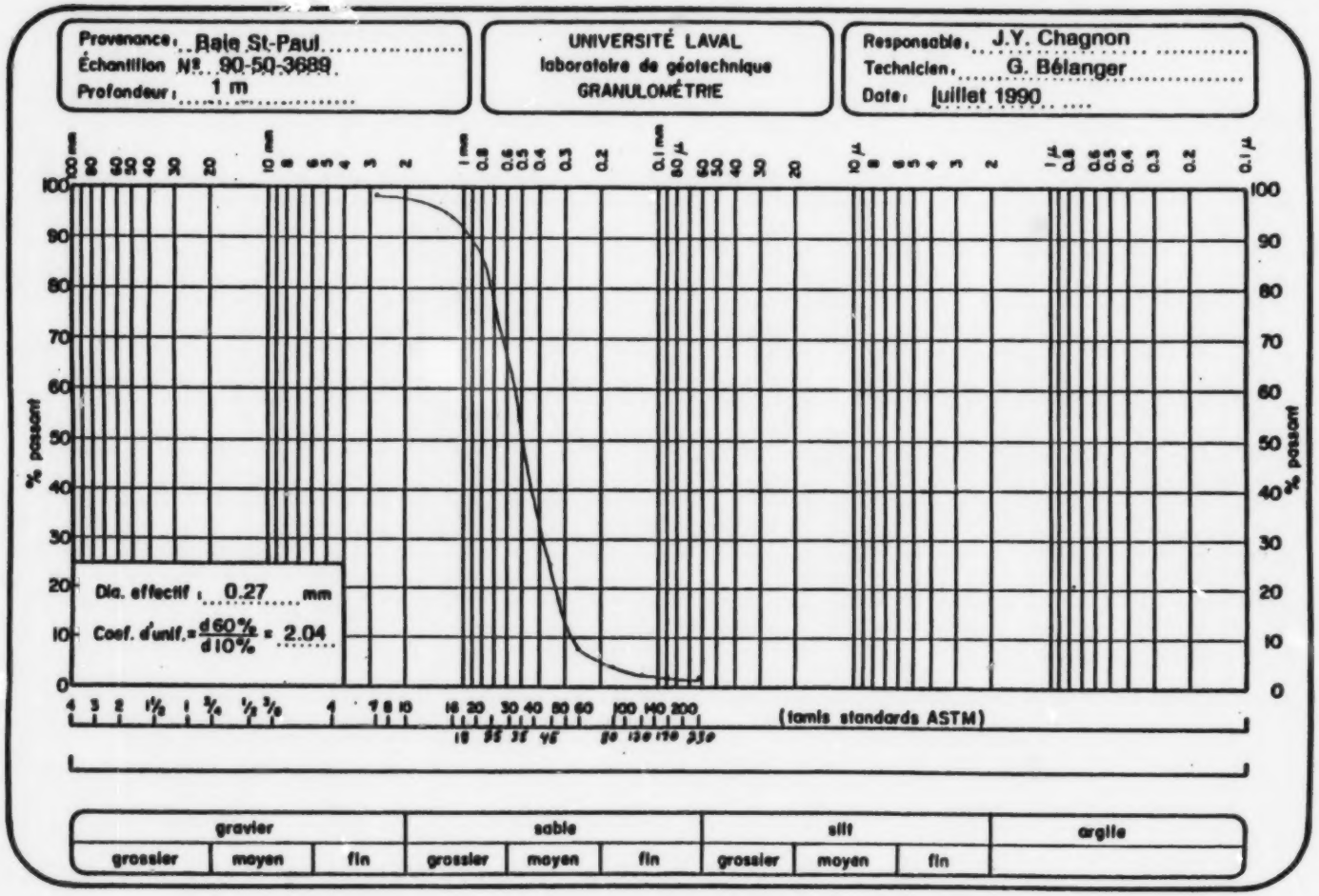


FIGURE 16 GRAIN SIZE ANALYSIS - SAMPLE 2

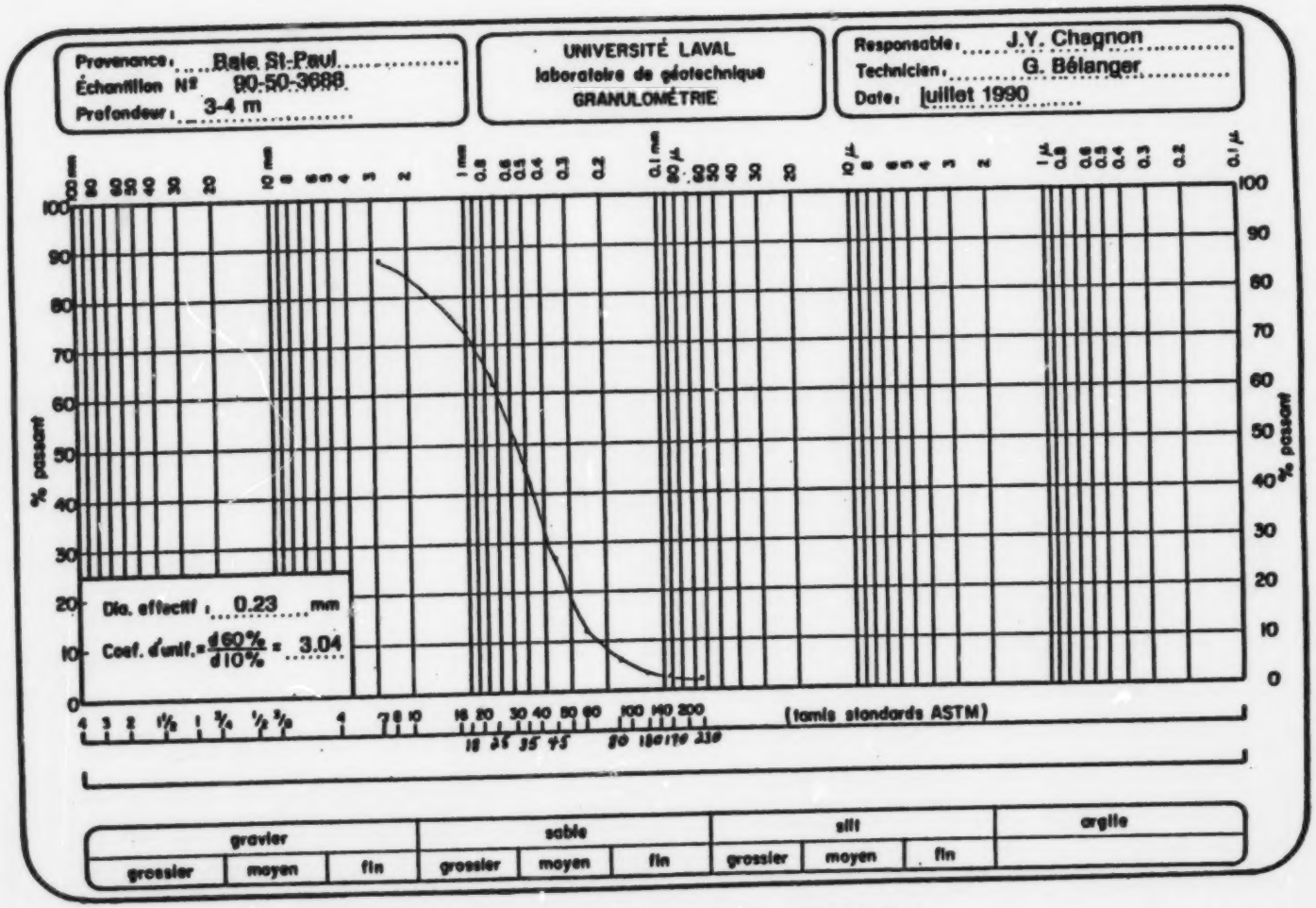


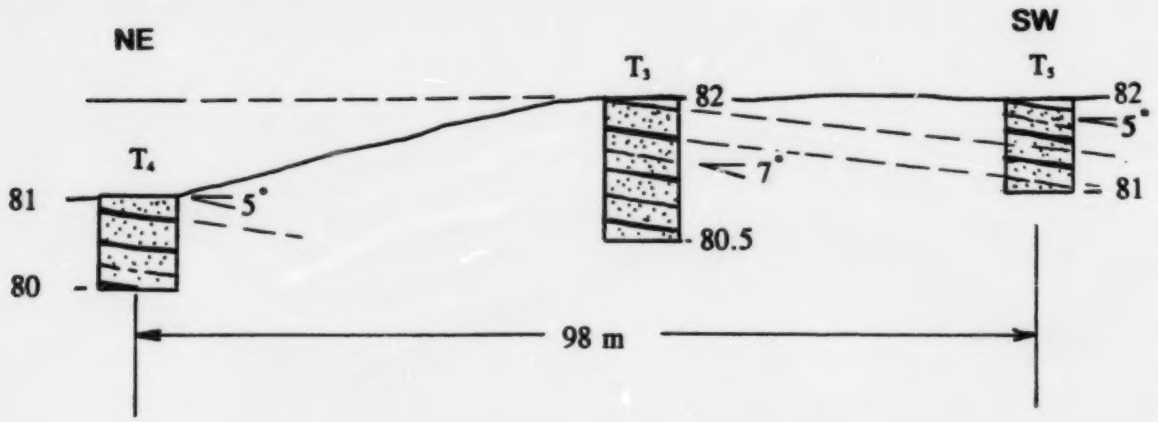
FIGURE 17 GRAIN SIZE ANALYSIS - SAMPLE 3

No macrofossils were observed in any of the excavations. Microscopic examination of the samples yielded no evidence of microfossils (foraminifera were not observed). The water table being lower than the depth excavated it is likely that fossils were dissolved by rainwater. Fossils (shells of marine origin) were observed in clay at levels under that of the terrace.

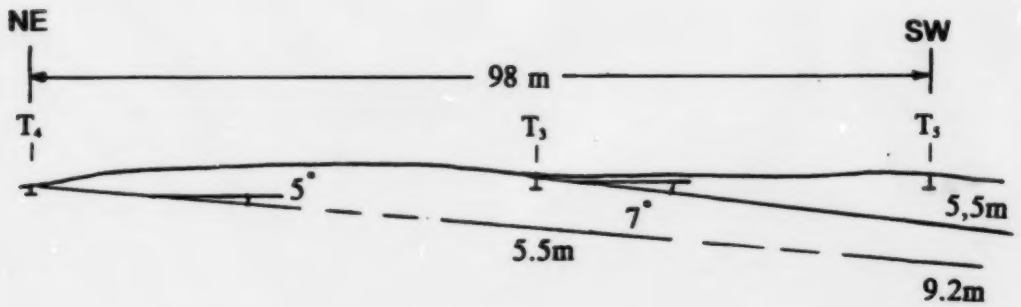
Trench T_2 was excavated near the western edge of the terrace at a surface elevation of 109 m down to an elevation of 107 m. Material very similar to that observed in the first trench was found but the sequence was different, as shown in Figure 14a and Photograph 3. The layers are also planar and parallel except for a narrow channel (Photograph 3). The second trench is 45 m to the west of the first one and, as shown in Figure 14b, the upper and lower elevations (109 and 107 m) are within the lateral continuity of the layers excavated in the first trench considering the dip of the layers observed in both trenches. The beds show good lateral continuity over the length of each excavation and in the high resolution georadar profile (Figure 8).

b- Stratigraphy of the northern segment

No large trench was excavated on the northern segment because of the impossibility of taking heavy machinery up the steep slope on the western side of the terrace. Trench T_3 was excavated halfway across the width of the terrace to a depth of 1.5 m starting at an elevation of 82 m down to 80.5 m. The material observed there is similar to that observed in the two trenches on the northern segment. It is a succession of medium to coarse sand layers and thin dark ilmenite-rich sandy layers. Three other shallow (1 m) pits were excavated along georadar line 2 and at another locality further south (T_4, T_5 and T_6 on Figures 6). Figure 18a shows the relation between the excavations. The stratigraphy in the three pits is similar.



a - vertical scale = 6X horizontal scale



b - vertical scale = horizontal scale

FIGURE 18 STRATIGRAPHY - NORTHERN SEGMENT

c- Environment of deposition

From the grain-size analysis it is concluded that the material is very likely a beach deposit. The good sorting and the high content of subrounded particles near the surface is consistent with a beach environment where material is reworked continuously by wave action resulting in good sorting and rounding of particles. The apparent lateral continuity is also characteristic of storm beaches (Elliott, 1978). The absence of cross-bedding, of ripples and deformation is typical of material which was deposited in a quiet, shallow and low-energy stable environment. The lack of deformation features of this relatively thin deposit can be explained by the postglacial deposition of the terrace. Deposition probably occurred in an estuarine environment, with a constant inflow of fresh water from the Rivière Du Gouffre valley. The emergence of the shoreline due to isostatic uplift created a regressive system with deposits which were only slightly modified by erosion.

The eolian origin of the terrace as postulated by A. Mailloux (Chagnon, 1969) appears to be very unlikely because of the absence of features usually associated with eolian deposits such as large-scale, high-angle crossbeds, very thin stratification and ripples (Walker and Middleton, 1977). No evidence of ventifacts was observed at the surface of the terrace. Furthermore, the dominant winds do not come down the Rivière Du Gouffre valley but are from the northeast and more closely follow the orientation of the St. Lawrence River. These winds are most active in wintertime when they can have no effect on the ground which is frozen and covered with snow for a period of about 5 months.

d- Attitude of the bedding

The orientation of bedding observed in the trenches was determined by the use of a compass. Because of the gentle dips of the beds everywhere the determination of the orientation (strike) was difficult and had to rely on numerous readings along the walls of the trenches.

Southern segment: This segment of the terrace is the one closest to the St. Lawrence River and also the one with the highest elevation (141 m). The bedding orientation was measured in a vertical cut to the east of the site of the excavation, at the A end of georadar Line 1. The vertical cut is just outside the eastern limit of the terrace and it exposes fluvioglacial material similar to that observed at the bottom of the first trench (T_1). This material is oriented in a direction closely parallel to that of the Rivière Du Gouffre valley with a dip of 30-35° towards the valley. In trench T_1, near the eastern limit of the terrace, the upper sand beds are subhorizontal with an orientation of N-10°-E and a gentle dip of 3° towards the valley. The orientation is relatively constant but the dip increases gently with depth to a maximum of 6°. The glaciofluvial material under the sand intersected at the bottom of the trench has the same orientation as that found in the vertical cut, that is a strike closely parallel to that of the valley and a dip of 30° towards the valley. In the second trench (T_2), close to the western edge of the terrace, the strike of the beds is similar to that in trench no. 1 but the dip is steeper, varying from 6 to 8° to the west.

Measurements of the orientation of the layers were also made on a vertical cut along the road leading to the summer camp (Photograph 4). There the orientation is N-17°-E with a dip of 12° to the west (towards R. Du Gouffre valley). This cut is located at the western edge of the terrace and it is two-sided. It was therefore easy to get an accurate determination of the strike.

Northern segment: In trench T_3 located at the end of the segment, near the center of georadar line 2, the beds were oriented at a slight angle to the valley (N-6°-E) with a dip of 7° to the northwest. In another trench (T_5) located to the west of the first one, at the B end of georadar line 2, the orientation of the beds was similar with a 5° dip to the northwest. The orientation and dips were similar in pit T_4 dug at the eastern end of georadar line 2. In trench T_6 dug halfway across the terrace, 150 meters to the south of georadar line 2, the orientation of the beds is at a slight angle to the northeast of the valley trend with a strike of N-12°-E and a dip of 5° to the west.

The orientation of the beds is relatively constant on both segments and only the dip varies, becoming steeper at depth and on the outside edge of the terrace. The fact that the strike of the beds is not exactly parallel to that of the valley as would be expected of beds laid down on a beach following the contours of the land but with a gentle dip away from the shoreline can be explained by tilting of the terrace. Tilting to the north of an inclined plane oriented in a northwest direction, such as that of the terrace, along a center of rotation located some distance to the north will rotate the strike of the beds to the north. A minor tilt has a large effect on the angle of rotation of the strike. The lack of parallelism of the beds with the valley wall is consistent with the apparent tilt observed at the surface. It is probable that the inclination of the beds is less than that of the surface but this is difficult to measure because of the shallow angles of the beds.

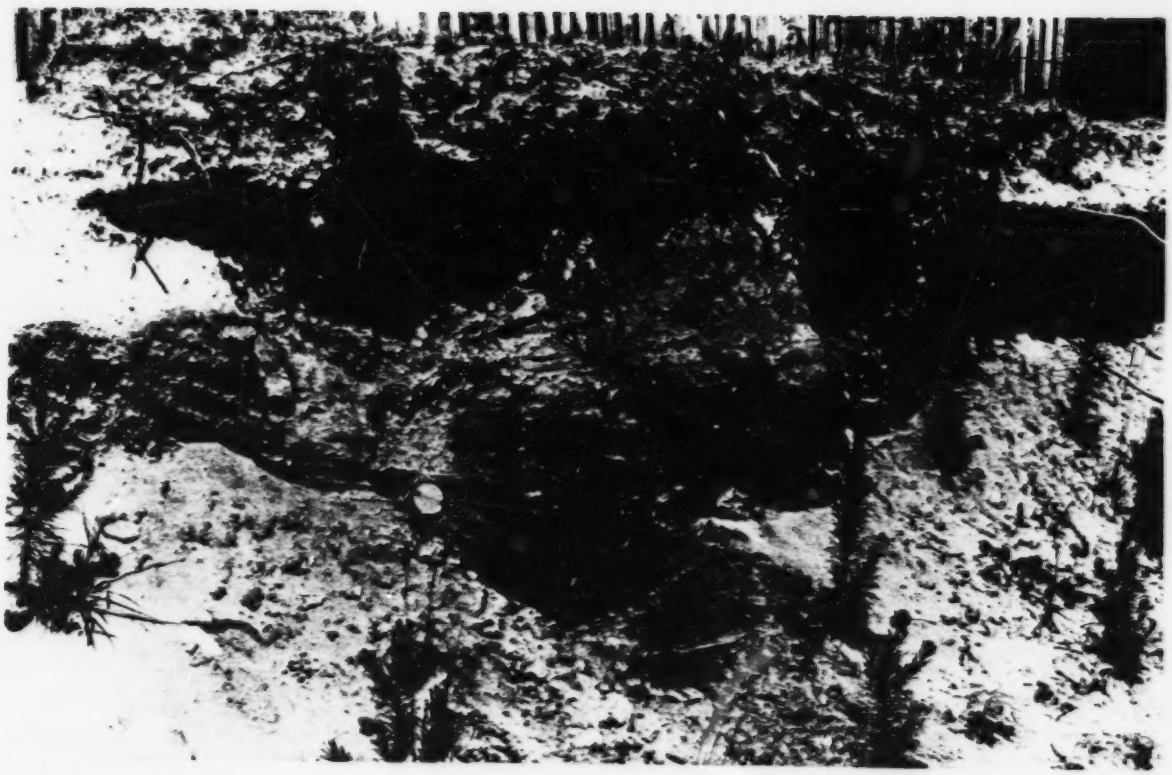
The orientation of the beds also indicates that the material at the south end has not been redeposited by other agents such as the wind which would have resulted in large differences in elevation, orientation and dips of the beds. The orientation measurements support the view that the beds have been tilted integrally after deposition.

e- Correlation of the stratigraphic sequence

Two trenches were excavated on the southern segment (T_1 and T_2). Figure 14b shows that the deposits observed in both trenches are very similar but that the sequence varies from one trench to the other. Figure 14b shows that the sequence observed in trench T_2 falls within the sequence observed in trench T_1 when the distance between the two trenches and the dips of the layers are taken into account and plotted with a vertical scale similar to the horizontal scale. The sequence in T_2 should correspond to that of trench T_1 between elevations 111 and 113. However Figure 14a does not show the same succession of layers with the same thicknesses for the corresponding cuts at the probable elevations. It is therefore not possible to establish a valid correlation of the stratigraphic sequence between the two trenches on the southern segment.

PHOTOGRAPH 2 - SOUTH WALL OF TRENCH T, (fluvioglacial material at bottom left) - depth = 4 m

PHOTOGRAPH 3 - NORTH WALL OF TRENCH T_2 - depth = 1.4 m



PHOTOGRAPH 4 - VERTICAL CUT ALONG ROAD ON SOUTHERN SEGMENT

This may result from small lateral variations in thicknesses or from the difficulty in determining the exact attitude of the beds. This determination is made difficult by the small dip of the layers and the large distance between the two trenches. A slight variation in the dip would result in a large vertical displacement of the sequence from one trench to the other. It is believed that this lack of correlation is normal considering the nature of the deposit which should increase in thickness as the distance from the shoreline increases. The thickness of the terrace sand was observed to increase to the west near the end of georadar line 1 (Figure 13) as shown on the georadar profile (Figure 11). A continuous trench along georadar Line 1 would show vertical variations in the terrace material as the thickness increases from nothing to 5 meters.

The trenches dug on the northern segment were at a much lower elevation (81 and 82 m) and were shallow. The observed sequences were similar to those found on the southern segment but it is not possible to ascertain that they are equivalent. Figure 18 b shows that the sequences observed in the three pits excavated close to georadar line 2 cannot be the same sequences because of the dip of the layers to the west. The sequence observed in T_5 is higher than that in T_3 which in turn is higher than T_4. These trenches would have had to reach depths of 5.5 and 9.2 m to show the stratigraphic horizons of trench T_4. This would not have been possible even with heavy machinery. None of the sequences is at the proper elevation to correspond to that of any of the other. Not only do small variations in the thicknesses of the layers make them appear different but changes in dip may move them vertically out of alignment with layers observed at a short distance. For this reaon only it seems unlikely that a good correlation could be made between the sequences on the northern and on the southern segments. The trenches would in all cases have to attain bedrock in order to cut a complete sequence and allow the establishment of correlation. Further the absence of an easily identifiable stratigraphic marker in any of the trenches prevented the identification of correlatable horizons. We do not believe that it is possible to establish a valid correlation of the stratigraphy between the northern and southern segments using the methods available for this study. More expensive techniques would have to be used (i.e. boreholes, seismic tomography, etc..).

III- SUMMARY AND CONCLUSIONS

The work was accomplished in relative conformity with the list of tasks to be performed presented in the contract document. The tilted terrace was investigated by precise levelling, two trenches were excavated, one on each side of the lineament, the stratigraphic sequence was documented, the environment of deposition was determined, the orientation of bedding was measured in all the excavations and an attempt was made to correlate the stratigraphic sequence between the two trenches. Furthermore a georadar survey was completed along two lines, one on each segment of the terrace.

The results obtained were not exactly as expected:

- The precision of the levelling was less than foreseen because of the impossibility of surveying the terrace from one end to the other along a single, continuous line. Because of obstacles the levelling had to be carried out independently on each segment and then had to be tied to a common reference point down in the valley by the main highway. Going up the steep slope along two different routes introduced errors in the levelling and the resulting precision is estimated to be of the order of 30 cm. An ordinary surveyor's level was used with a stadia rod graduated in tenths of centimeters. This type of instrumentation normally yields a precision of one centimeter when few turning points are used. But we had to use about twenty five on the terrace and more than 60 for each link down to the bottom of the valley and this is where errors were introduced. Because of the steep slope and the presence of numerous obstacles the sightings were numerous and covered very short distances. Errors were introduced at each step and we estimate the precision at no better than 30 cm.

The results of the altimeter survey had a precision of about 1 m. The elevations so determined were tied to the level survey and a few discrepancies between the two surveys were noted. We believe that the electronic altimeter used is erratic and may be disturbed by interference from power lines or other sources such as static electricity.

Segments of lower terraces were visible on air photographs. Some were located with difficulty in the field and were surveyed. Because of the absence of long sections we cannot compare the slopes of these segments with that of the terrace, except for one at elevations of 32 and 67 m over a distance of about 300 m. This segment shows a slope opposite that of the tilted terrace. This is not unexpected but this slope may have been tilted up in the direction of the upper terrace by an unknown amount.

The two trenches which were to be excavated were to be located on each segment of the terrace. It was found that a trench on each segment was not sufficient to cover the width of the terrace, unless a continuous trench of a length of about 90 m was excavated. This was impossible on the southern segment because of the presence of vegetation which was not to be disturbed and on the northern segment for the same reason and also because heavy excavation machinery could not access the terrace. Two trenches were dug with a backhoe on the southern segment along a line perpendicular to the length of the terrace with a backhoe. The depth attained was the maximum which could be reached with this instrument. Water was not a problem as the ground was well above the water table. The only limit to depth was the length of the arm of the backhoe. On the northern segment five excavations, four small pits and one trench, were completed with hand shovels. The depth of excavation was limited by the slumping of the material as the dry material on the walls collapsed back into the excavations. Deeper trenches would have been preferable and might have yielded more useful information.

The georadar survey was successfully completed on both segments. The results on the southern segment were excellent and those on the northern segment were good. This conclusion is based on the diagrams obtained and on the field verifications (trenches and outcrops). This is somewhat surprising because the material was dry at and near the surface and only slightly damp at depth. The presence of water is considered necessary to increase the contrast between the dielectric properties of the material and thus give rise to reflections. In this case the material contains components

of widely varying and contrasting electrical properties, such as ilmenite-rich layers and this is the probable reason for the good results. At depth the fluvioglacial material is more compact than the loose sand near the surface ant the amount of interstitial water is also greater. This explains the strong reflections obtained. The bedrock also shows strong reflections, both at the contact with the overlying fluvioglacial material and along the internal discontinuities.

- The orientation of the beds was measured in all the trenches and along a road cut on the southern segment. An unexpected difficulty was the shallow dip of the beds which made it difficult to measure precisely the strike along a single vertical wall. The shallower the dip the less precise is the measurement of the strike, because it is very easy to introduce large errors in the reading of small angles. In the best conditions a spirit level would have to be used along two adjacent walls (at right angle) of the trench. This was not possible because it was unsafe to stay in the trench for more than a few minutes because of the everpresent danger of wall collapse. Many readings were made however, but a certain degree of imprecision has to be acknowledged.

- A valid correlation between the layers in the trenches on both segments of the terrace was not achieved. This results from the shallow dip of the beds and from the large difference in elevation between the trenches on each segments (110 m on the south and 80 m on the north). The slope of the surface of the terrace and that of the beds are very similar and the total thickness of the sand horizons over the glaciofluvial material is also similar, as indicated by the georadar survey. For these reasons it is considered that the material observed on both segments belongs to the same horizons. But there are differences in the layering of the material (different sequences, thicknesses and composition) and in the absence of marker horizons it is not possible to establish a definitive correlation. These differences may result from lateral gradations but could also be interpreted as indicating that we are not observing the same horizons.

The limited means used could not allow the precise determination of all the various parameters needed to arrive at a definitive conclusion. However much was learned about the inclined terrace and some parameters are well identified and a few conclusions can be reached:

- **Origin of the material**: The material is typical both in composition and structure to that of a beach deposit in a marine or estuarine environment (grain size distribution, sorting, shape and roundness of the particles, planar beds and lateral continuity). The terrace is not an erosional feature and is not the result of eolian activity.

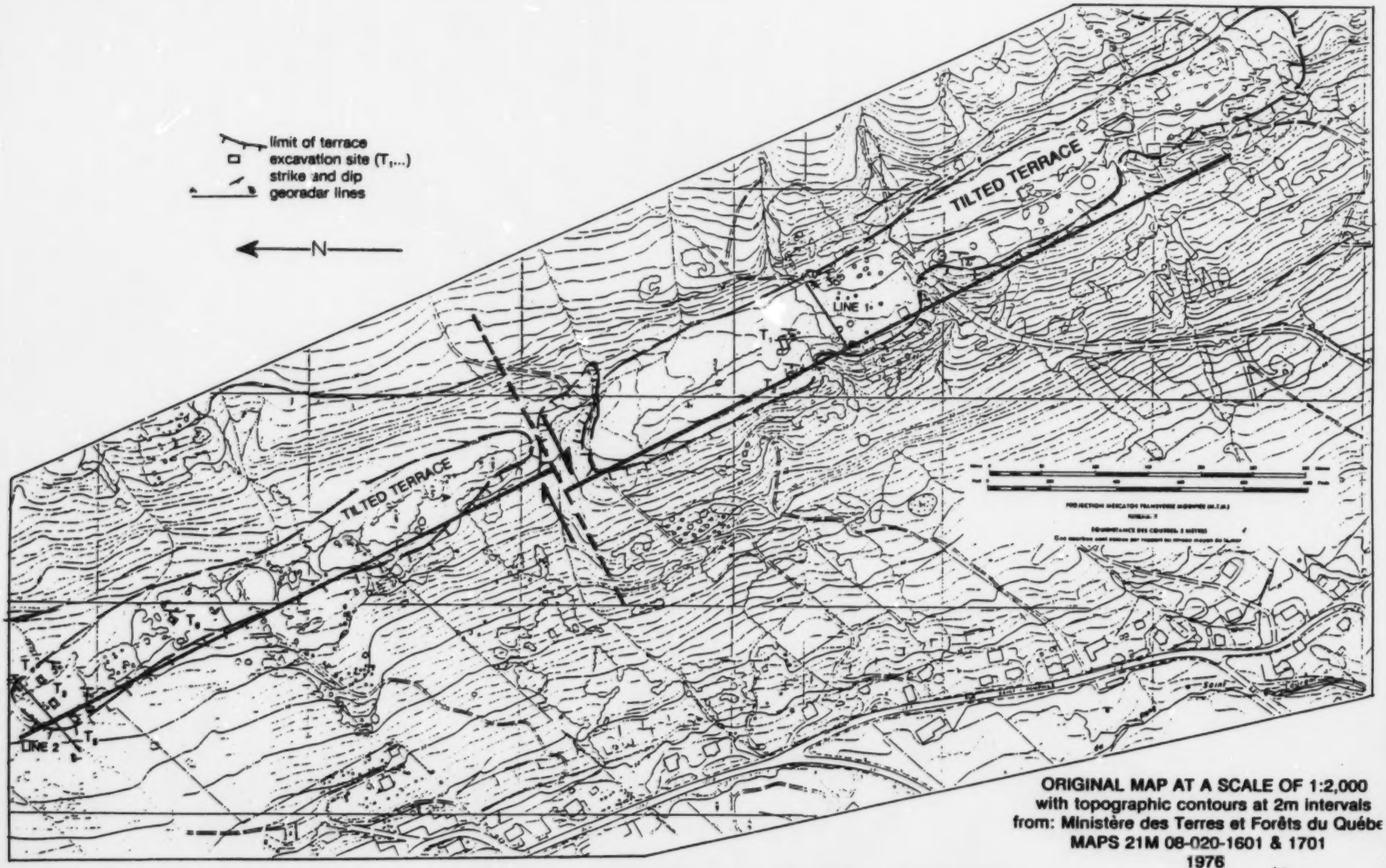
- **Tilting of the surface**: The northward inclination of the surface is more than apparent, it is real. The inclination of the surface as measured by levelling has angles varying from 2.1 degrees for the northern segment to 3.21 degrees for the southern segment (over a combined length of 1256 m). The measurements of the orientation and dips of the beds indicate that the beds are also inclined along the same slope as that of the surface. Their orientation is now at an angle with the trend of the valley wall but one must assume that the beds were initially deposited with a trend parallel to the valley. Their orientation appears to have been rotated by the tilting. The origin of the tilting is tectonic and cannot be associated with dynamic agents such as wind.

- **Vertical displacement**: The two segments of the terrace show no indication of vertical displacement. A view from across the valley (Figure 1) gives the impression that a large vertical displacement has occurred. This is an illusion resulting from the fact the the viewpoints available are not perpendicular to the terrace, but are all at an angle and provide an oblique view with consequent distortion. The two segments of the terrace were levelled independently and then tied to each other. A difference of less than 1 meter was found. Because of the large imprecision of the survey we consider the vertical offset to be minor if it exists at all.

- **Horizontal displacement**: The horizontal displacement is apparent on air photographs and topographic maps. It is indicated by the western limit of the terrace or by the steep slope limiting its width. Air photographs are influenced by the lack of vegetation at the surface and do not provide a reliable indication. Topographic maps with contours at two meter intervals show an offset in the western limit of the terrace (Figure 19). This is not apparent on the eastern limit, where the terrace abuts the valley wall, because the contact with the valley wall is not sharp on the northern segment due to the presence of a stream parallel to the contact. The apparent offset is relatively minor, of the order of 20 meters. It shows a right lateral slip as predicted by Kumarapeli (1987). We must emphasize however that this offset is **apparent** and has not been corroborated by other evidence (geologic, geomorphic). The displacement is not associated with a known fault. Rondot (1979) showed numerous faults, one of which (Figure 2) intersects the terrace at right angle, much as in Figure 19. However Rondot (1979, 1989) did not show this fault on other maps shown in Figures 3 and 4.

- **Correlation**: No correlation was established between the beds excavated in the two segments of the terrace. However the two segments are aligned along the angle of tilt and the layers are inclined along an angle similar to that of the surface. They are probably the same beds but with modifications caused by lateral gradations.

- **General conclusion**: The terrace is a marine or estuarine feature associated with the invasion of the Goldthwait Sea. There is evidence that the surface of the terrace and that the layers below the surface are inclined in the same direction. This tilting is not the result of eolian activity but is probably tectonic in origin. There is no indication of a vertical offset at the point where the terrace is separated in two segments but there is indirect evidence of lateral offset along this discontinuity. The lower terraces are inclined in the other direction. We have no indication as to the age and rate of the tilting, which is probably younger than 9,000 years B.P.



ORIGINAL MAP AT A SCALE OF 1:2,000
with topographic contours at 2m intervals
from: Ministère des Terres et Forêts du Québe
MAPS 21M 08-020-1601 & 1701
1976

FIGURE 19 INTERPRETATION OF THE TOPOGRAPHY

IV- RECOMMENDATIONS

If further work is considered useful and/or necessary we would recommend the following:

- Run a more precise and complete survey of the area. The available maps are not accurate enough to allow a precise determination of elevations. The levelling survey should be run with more precise and longer range instruments than the ones used. It might be preferable to have the survey done by a specialist in that field (undoubtedly at great cost).

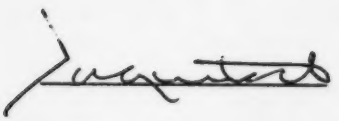
- Run a seismic refraction survey perpendicular to the trend of the terrace on both segments to identify the depth to bedrock. Seismic reflection using shear waves would be useful in determining the position of the contacts along a continuous profile.

- Drill boreholes with continuous sampling and oriented cores down to bedrock along two sections perpendicular to the trend of the terrace, one on each segment. Three boreholes by section would be needed. Geophysical logging in each hole would be useful for the identification of marker horizons. This is necessary to complement the excavations already performed. It would be difficult and rather expensive to bring a drill up the slope, but it can be done. The depth of investigation would not exceed ten meters, and in most cases would be less than five meters.

- Complete a magnetic survey across the discontinuity between the two segments of the terrace (such work was undertaken two years ago by geophysics students at Laval university and an anomaly was detected - this work was not documented). A fault such as the one shown on the geological map prepared by Rondot (1979 - Figure 2) might be outlined and this would help confirm the probable offset between the two segments.

Ste-Foy, April, 1991

Jean Y. Chagnon



Jacques Locat

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ANNEX I

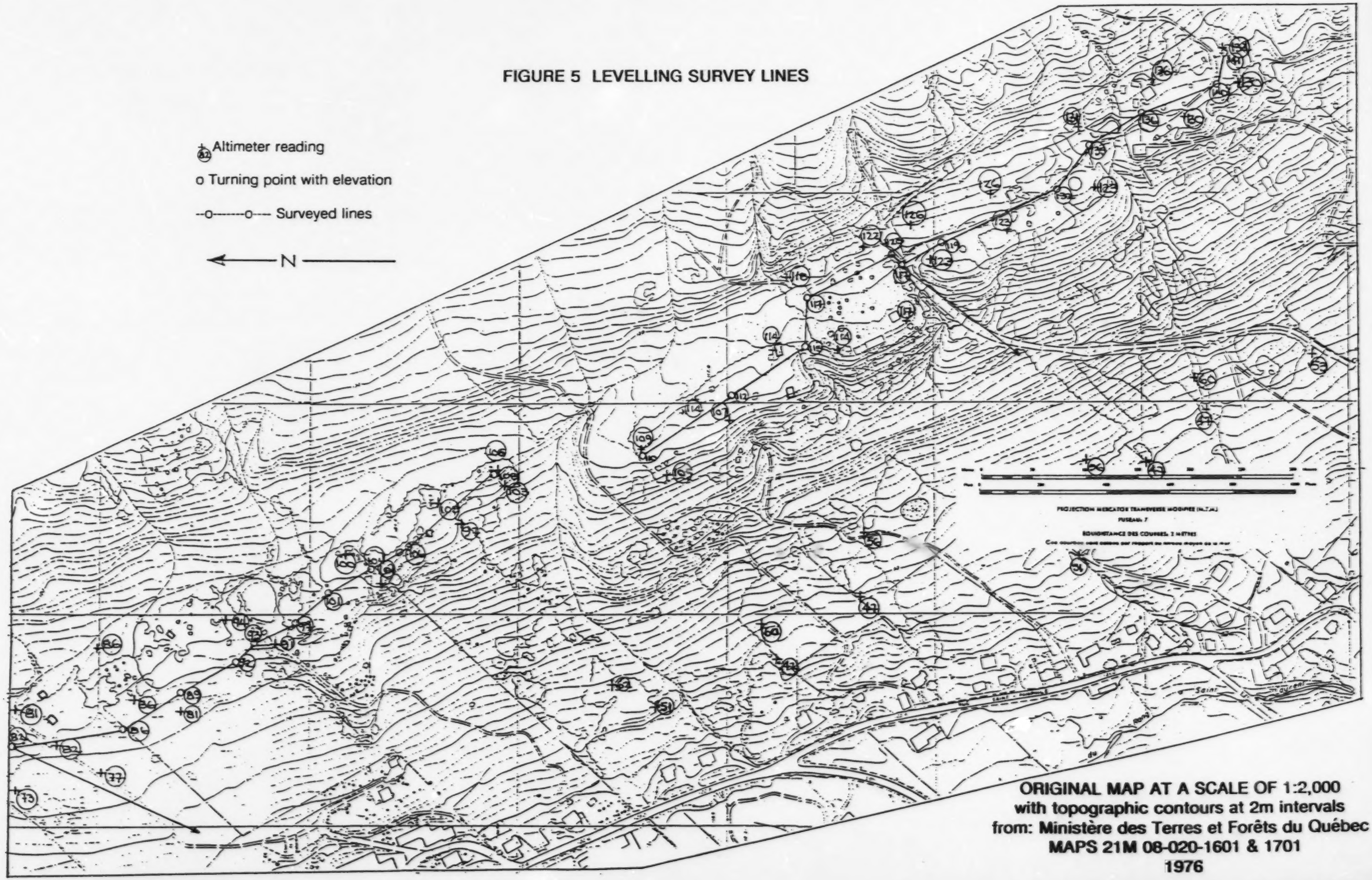
FIGURE 5 LEVELLING SURVEY LINES

Altimeter reading

o Turning point with elevation

--o------o--- Surveyed lines

← N



ORIGINAL MAP AT A SCALE OF 1:2,000
with topographic contours at 2m intervals
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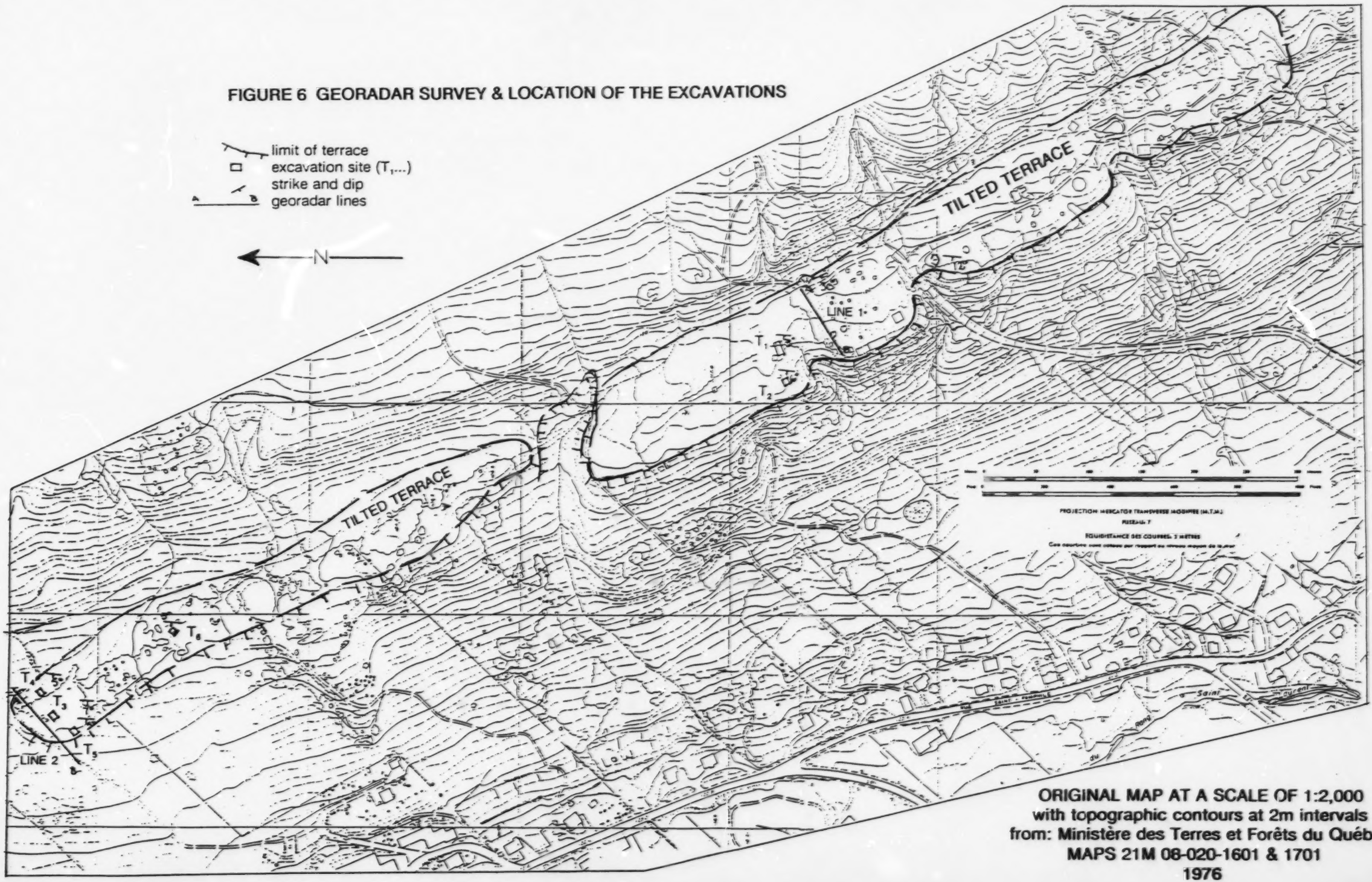
1976

FIGURE 6 GEORADAR SURVEY & LOCATION OF THE EXCAVATIONS



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